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A CONCEPTUAL COST MODEL FOR UNCERTAINTY PARAMETERS AFFECTING NE--ETC(U)

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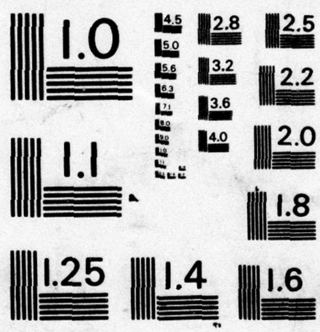

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

A CONCEPTUAL COST MODEL FOR UNCERTAINTY PARAMETERS AFFECTING NEGOTIATED, SOLE-SOURCE, DEVELOPMENT CONTRACTS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

MARTIN DEAN MARTIN

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A CONCEPTUAL COST MODEL FOR UNCERTAINTY PARAMETERS AFFECTING NEGOTIATED, SOLE-SOURCE, DEVELOPMENT CONTRACTS

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Martin Dean MARTIN, Ph.D.
The University of Oklahoma, 1971

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In recent years much attention ~~has been~~ was placed on cost growths as related to the acquisition of weapons systems by the military services. Uncertainties exist relative to program costs, delivery dates, and product reliability. The purpose of this study is to construct a model which will assist in coping with uncertainties affecting cost. Research and development procurement is unique. A goal is purchased, not a hardware item. Vague specifications may cause contract costing problems. The weapons acquisition process encompasses concept formulation, contract definition, engineering development, and production and operation. As a scientific concept traverses the continuum from concept formulation to production, uncertainties are reduced.

For this study, uncertainty cannot be distinguished from risk. Thus, they may be considered synonymous. Uncertainty may be classified as either anticipated or unanticipated. Each of these is classified as either exogenous or endogenous. Uncertainty is the absence of information, which may be though of as a commodity. In this capacity, information may be described and measured. Information gleaned from the internal and external environments will permit the reduction of uncertainty. The military services have attempted to cope with uncertainty by the use of incentives and contractual arrangements.

The relationship between the entropy, information, uncertainty, and cost parameters enables a conceptual cost model to be developed. Entropy is a measure of information in a system. The term refers to magnitude and not meaning. Informational efficacy relates to the meaning of a message. The effective cost for a program may be represented by the ratio of target costs to the informational efficacy of the data in a closed system. As entropy ~~increases, information~~ increases, uncertainty increases, freedom of choice increases, but the informational efficacy decreases. One result of the model is the derived requirement for a total economic cost approach to weapons acquisition. A balance must be sought between economic program cost and administrative cost. A startling development is that a cost growth for a specific contract may be less costly than the actions necessary to preclude its occurence. Order No. 72-14, 111, 199 pages.

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A CONCEPTUAL COST MODEL FOR UNCERTAINTY PARAMETERS AFFECTING NEGOTIATED, SOLE-SOURCE, DEVELOPMENT CONTRACTS

CHAPTER I

INTRODUCTION

In recent years much attention has been placed on the subject of cost growths as related to the acquisition of weapons systems by the military services. Peck and Scherer in a study of the weapons acquisition process found that the average development cost prediction error for a sample of 12 weapons programs was 220 percent with a standard deviation of 170 percent.[1] A congressional list of 35 major weapons systems disclosed that 27 of the programs involved cost growths totaling 19.9 billion dollars.[2]

Simplicity appears to be the key characteristic of a contracting relationship between any two groups. For a

[1] Merton J. Peck and Frederic M. Scherer, The Weapons Acquisition Process (Boston: Harvard University Press, 1962), pp. 17-45.

[2] "Defense Digest," Armed Forces Management, January, 1970, p. 17.

stated amount of money the contractor agrees to deliver to the governmental agency a product at a specific time in a stated quantity. A definite level of performance is also specified. Investigation reveals that the relationship can be a complex one, having a large number of interacting variables.

The final contract price which results between the government and the commercial contractor is based on estimates of future costs. The estimates relate to the unknown future and are at best approximations which may involve considerable error. The more ambiguous and vague the specifications for the product or service being purchased the larger the potential range of error.

Uncertainties exist relative to program costs, delivery dates, and product reliability. The uncertainty parameters for a given weapon system will evidence themselves most dramatically in the area of costs.[3] Delivery schedules and reliability are directly related to costs. If the contractor is willing to expend unlimited funds in the face of technological or other problems, then the delivery schedule can be accomplished with the required degree of product quality. However, unlimited funds are not generally available. Firms face various funding constraints. The need is

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[3]Robert J. Art, The TFX Decision (Boston: Little, Brown and Company, 1968), p. 86.

to create an approach for dealing with the program uncertainties which are relevant.[4]

Thus, the purpose of this study is to construct a conceptual cost model that will assist the government and its contractors in coping with the uncertainty parameters which could affect the costs of a sole-source, negotiated, development contract. The type of contract selected to support a given program is at present the primary technique used to cope with this cost uncertainty. The goal is a better understanding of the weapons acquisition process that will result in the minimization of program and total-system costs.

The methodology of the study is predicated primarily on a survey of the pertinent procurement literature relating to government procurement and uncertainty analysis. The approach is eclectic as different concepts are selected from various sources for use in model building. Some observations will be based on personal experience with the research and development portion of the weapons acquisition process. Pertaining to the weapons acquisition process and government procurement practices, an average level of sophistication is assumed.

Scherer states that a survey of the literature has limitations and is no substitute for careful empirical

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[4]C. J. DiBona, Where Is Systems Analysis? (Arlington, Virginia: Center for Naval Analyses, 29 April 1969), pp. 6-7.

research.[5] This limitation is acknowledged. However, research on individual development programs is extremely complex and time consuming. Considerable difficulty has been experienced in trying to compile detailed cost data and case histories for military research and development programs.[6]

A model is an abstraction from reality and has certain inherent limitations. The variables in a specific model interact with the larger system of which the model is a part. This factor requires some variables to be held constant as one or several others are manipulated. However, even with abstractions a model may have utility if the result is a better understanding of the subject being examined. Additionally, some factors defy quantification.[7] These qualitative considerations can be evaluated and reviewed during the decision-making process, so as to minimize the possibility of a suboptimal decision.

At the outset the study will consider the broad aspects of the weapons acquisition process. This material will furnish the foundation for later parts of the paper.

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[5]Frederic M. Scherer, The Weapons Acquisition Process: Economic Incentives (Boston: Harvard University Press, 1964), p. 14.

[6]Burton H. Klein, The Decision-Making Problem in Development (Santa Monica, California: The RAND Corporation, February, 1960), p. 2.

[7]Philburn Ratoosh, "Defense Decision-Making: Cost-Effectiveness Models and Rationality," in Weapon System Decisions, ed. by Davis B. Bobrow (New York: Frederick A. Praeger, Publishers, 1969), p. 30.

The specific focus will be the development portion of the research and development spectrum. Efforts to reduce uncertainty must start early in the program. Maximum effort can be applied to minimize developmental costs. At this point, the concern is with subsystems which will later be aggregated to form a given weapon system. However, the various parts of the weapons acquisition process are interrelated, and subsequent discussions will reflect this interdependency.

Costs growths may occur as the result of post-acquisition actions, and this fact will be considered in terms of the model that is developed. The model will reflect the static nature of the procurement-planning period. Costs are to be estimated for a future period. The future is replete with uncertainty. This uncertainty needs to be reduced to increase the efficacy of defense decisions. Dynamic aspects of the situation will be considered. The passage of time will validate or refute the actions taken during the prenegotiation phases of the procurement cycle. High-quality information is necessary to determine the status of program costs at any point during the program. Such data will be the basis for decisions to effectively control costs.

Thus, the detailed plan evolves from the general to the specific. Chapter II introduces the research and development spectrum, and other significant procurement concepts. The weapons acquisition process and the procurement

cycle are the important aspects of Chapter III. The defense industry and certain of its characteristics are the prime topics of Chapter IV. In Chapter V the measurement of risk and uncertainty is examined. A consideration of contractual incentives follows. The cost growth problem is considered in Chapter VII, and in Chapter VIII the attempts to cope with the cost-growth problem are explored. Chapters IX and X develop the general and specific versions of the model. The final Chapter contains the conclusions.

CHAPTER II

RESEARCH AND DEVELOPMENT PROCUREMENT

Environmental change requires the modification of weapons. A given weapon must conform to the current technological state-of-the-art. This necessity often stimulates the creation of new and more complex weapon systems. Another stimulus affecting system and system component change are the operational problems. They become apparent as a weapon is required to perform over an extended time period and in several different capacities. The necessity for new ideas and the derived applied concepts is a constant characteristic of the military-planning environment. Many ideas result in no meaningful technical progress. The only beneficial conclusion is that the technical approach under consideration will not work. The process leading from an idea to a system component or system can be thought of as a constantly evolving spectrum.

The Research and Development Spectrum

The continuum originates with the research stage and continues through exploratory and advanced development to

engineering development. The latter is often referred to as full-scale development. The nature of the spectrum is dynamic when considered from the standpoint of more than one idea. New ideas have their genesis at each stage of the spectrum, so the continuum is constantly being expanded. The first three stages are preacquisition in a system context. In the full-scale development stage the term, acquisition, has meaning. The four stages are considered below.[1]

Research.--This stage envisions research for its own sake. Basic research and those elements of applied research which are directed toward the expansion of scientific information are included. The over-all goal is an expansion of general knowledge in the physical, biological, medical, behaviorial, social, and engineering sciences. A project may yield only the information that a specific technique will not work.

Exploratory development.--As contrasted to research, the goal is to explore the feasibility of applying new ideas to military weapons and equipment. Now a part of the stage, applied research was the descriptive term for the whole stage several years ago. The spectrum classifications are somewhat arbitrary and overlapping.[2] The budget process in the main

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[1] Charles J. Hitch, Decision-Making for Defense (Berkeley, California: University of California Press, 1965), pp. 36-37.

[2] Arthur Ahlin, "Firm Fixed Price Contracting for Development," NCMA News Letter Anthology, Vol. No. 1,

dictates the lines of demarcation to be established. Exploratory development is more delimited. The product of the research stage may be a technical report. In exploratory development the result may be a prototype or "bread-board" model.

Advanced development.--The effort is narrowed in this stage. The goal is the application of the idea to a specific military purpose or problem. Experimental hardware is developed and tested for its suitability to military purposes. If the tests are favorable, a decision may be forthcoming to design and engineer the component for actual service use. The program scope can vary widely.[3] For example, North American Aviation's X-15 required expenditures of tens of millions of dollars over many years, and the Advanced Manned Strategic Aircraft (AMSA) cost eighty million dollars to develop.

Engineering development.--This stage encompasses the development of a particular system engineered for specific service use but not yet approved for production and deployment. The C-5, F-111, and F-15 are examples of aircraft that experienced cost problems during the stage.

1968-1969-1970 (Inglewood, California: National Contract Management Association, June, 1970), p. 105.

[3]Martin Meyerson, "Price of Admission into the Defense Business," Harvard Business Review, July-August, 1967, p. 116.

Nature of Research and Development Procurement

The costing of a given program is most difficult in the research stage. The specifications are represented by a rather vague and nebulous statement of work. The purpose of this work statement is to furnish the contractor general guidance, and to restrict the effort to a given scientific field. Yet, the guidance must not be too rigid or the academic freedom of the researchers may be abridged. Stringent curtailment of academic curiosity may stifle the spark of creativity mandatory for scientific progress. When this condition prevails, the end result is a wasted expenditure of funds. A knowledge of what is being purchased is the key to the preparation of individual cost estimates. Each cost category needs to be explored to determine its extent and the bases for possible cost variations. These estimates will be aggregated to determine total contract costs. This same generic type of problem is inherent in the other three stages. However, as the spectrum is traversed the specifications become more definitive. The core of the problem is that a goal or series of goals are being obtained, not a hardware product. The research and development spectrum occurs in an environment characterized by technological, cost, and other related uncertainties. In the area of uncertainty, the unknowns are greatest in the research stage, and decrease as a program passes across the spectrum. The uncertainties decrease over time. For the contractor the need is to accelerate risk reduction.

Program Origination

Technological change stimulated by the passage of time may induce the awareness that a certain type of weapon system must be developed or improvements made to an existing system. Plans are formulated and a definite requirement is substantiated. The desideratum for an advanced development program may be the result. The agency responsible for action will attempt to translate the requirement into detailed specifications. The next step is to locate the government activity best suited to conduct the program. Assuming no military agency has the capability, a civilian source will be utilized.

The program may be unique and require technical specialization. In this instance, only one source will be solicited. Increasing complexity and the growth in scope of weapon systems has permitted such specialization. For example, a firm develops an expertise in inertial guidance for missiles. Faced with a limited market, the firm is able to exist by product specialization. This type of procurement is designated sole source and means that one source was solicited. A sole-source situation exists also when only one firm is available, and submits an unsolicited proposal. Studies by the Logistics Management Institute have revealed that in fiscal year 1969, sole-source procurements accounted for 60 percent of the total procurement dollars and 73

percent of the total procurement actions.[4] The significance of this condition is the monopolistic market relationship which results. Competition is not a stimulus to regulate cost. Instead, possible methods of controlling program costs are the focal point of negotiations.

In some cases, competition can be part of the acquisition process. When this situation occurs, proposals are solicited from several firms, having products or services which are close substitutes for one another. A source file is reviewed, and those contractors which appear technically qualified are requested to submit proposals. In fiscal year 1969, 40 percent of the procurement dollars and 27 percent of the procurement actions were categorized as multi-source competitive solicitations.[5]

The requirement for a change to an existing weapon system or for the development of a new one may be detected by an individual firm in the defense industry. The technical proposal is prepared and submitted to the pertinent military service on an unsolicited basis. Such a situation will generally result in a sole-source procurement action, if the proposal is deemed technically acceptable. This type of business practice is often advantageous to defense firms.

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[4]Logistics Management Institute, Briefings on Defense Procurement Policy and Weapon Systems Acquisition (Washington, D.C.: Logistics Management Institute, December, 1969), pp. 26-27.

[5]Ibid.

Should the development project be successful, the firm based on its technical knowledge is almost certain to receive follow-on procurements for continued development. Eventually, the firm may even receive a sole-source-production contract.

The economic significance of sole-source procurements is that competition is not available to stimulate efficient resource allocation. Cost estimates are based on historical data. Perhaps inefficient operations in the past form the basis for cost data, then average total costs will be higher than warranted.[6] Studies have disclosed that adequate specifications plus two or more qualified sources can result in reductions in price of about twenty-five percent on the average.[7]

Contract Placement

The U.S. Government maintains a limited public-owned laboratory and production capability. Consequently, goods and services are primarily procured from the private sector of the economy. Procurements are placed by two methods.

Formal advertising.--By statute advertising is the preferred procurement-placement methodology. The goal is to

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[6] James E. Hibdon, Price and Welfare Theory (New York: McGraw-Hill Book Company, 1969), p. 264.

[7] The Southwestern Legal Foundation, Government Contracts and Procurement (New York: Commerce Clearing House, Inc., 1963), p. 207.

obtain the highest degree of competition possible.[8] This method is best for items standard in nature with a fairly long record of production, such as food products, automotive parts, clothing goods, and furniture. The required goods are detailed in a public advertisement that solicits bids from all companies wanting to participate. Respondents submit sealed bids which are opened at a specific time and place under very rigid procedures. The procurement is awarded to the lowest bidder. Research and development projects seldom conform to the criteria for formal advertising.

Negotiation.--Procurements not placed by formal advertising are generally placed by negotiation. The Logistics Management Institute cites two basic differences between advertising and negotiation.[9] First, no public opening of bids occurs, and secondly, the award does not necessarily go to the lowest bidder. This second factor results from the premium placed on technical competency. Price is certainly a factor considered in research and development. However, the need for a high-quality product and the best over-all contractual arrangement may override price considerations. On the average, approximately 90 percent of all defense

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[8]U.S., Department of the Air Force, Air University, Extension Course Institute, Introduction to Air Force Procurement, Vol. 1, Course 6500, Procurement Officer (Amarillo Air Force Base, Texas: Air Training Command, 1 April 1971), pp. 1-3.

[9]Logistics Management Institute, op. cit., pp. 2-3.

contracts by dollar volume are contracted on a negotiated basis.[10] To be more specific, in fiscal year 1970 the percentage of negotiated procurements was 88.6.[11]

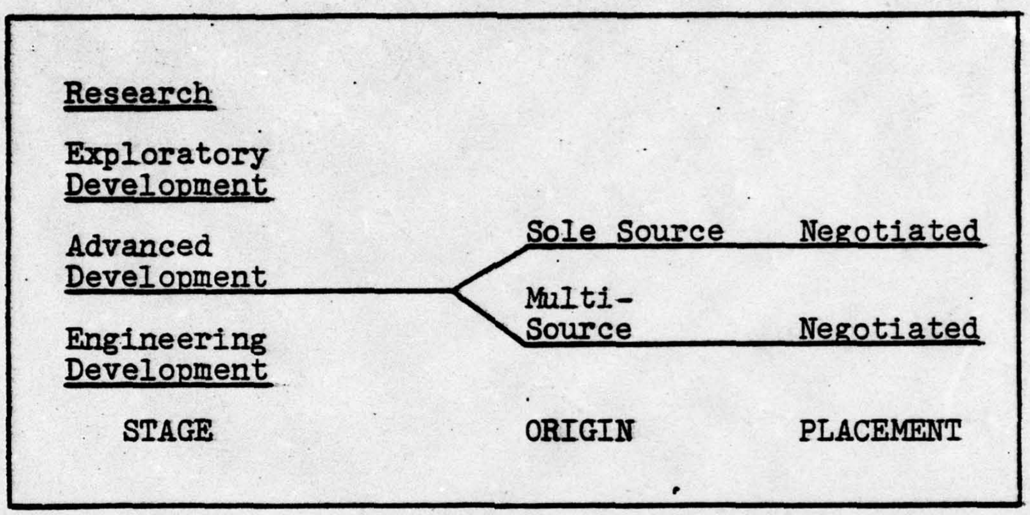

Fig. 1.--Procurement concept relationships

Graphic Summary

The procurement concepts considered in this chapter are related and interdependent. (See Figure 1.) The advanced development network is the only one extended; however, the same alternatives exist for the other stages.

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[10]"The Profit Puzzle in Procurement," Business Week, March 6, 1971, p. 44.

[11]"Defense Profits to Rise," The Norman (Okla.) Transcript, June 1, 1971, p. 3.

CHAPTER III

THE WEAPONS ACQUISITION PROCESS

The research and development continuum encompasses research, exploratory development, advanced development, and engineering development. The total weapons acquisition process is obtained by adding the production and operational deployment phases. Definitionally, weapons acquisition is the conception, development, and production of technically advanced weapon systems.[1] A weapon system represents an integration of individual parts to form a complex whole. Operational, maintenance, and other support functions are included.[2] An airplane, submarine, tank, or ship are examples.

Weapon Acquisition Phases

From a contractual standpoint the weapon procurement process can be segmented into four phases. (See Figure 2.) Conceptually, this subdivision permits contracts to be

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[1] Scherer, op. cit., p. 1.

[2] Logistics Management Institute, op. cit., p. 35.

negotiated at the beginning of each phase, so as to encompass the program effort contemplated for the pertinent segment.[3]

Topic	Subdivision		
Weapon Acquisition Process	Concept Formulation	Contract Definition Engineering Development	Production and Operation
Research and Development Spectrum	Research Exploratory Development Advanced Development	Full-Scale Development	Production

Fig. 2.--Research and development conceptual integration

Source: Hudson B. Drake, "Major DOD Procurements at War with Reality," Harvard Business Review (January-February, 1970), pp. 129-131.

Concept formulation.--This phase includes the research, exploratory development, and advanced development parts of the research and development spectrum. Since the advanced development phase is included, and a sequential progression is involved, a specific military application is contemplated. Experimental hardware is developed on a prototype basis and tested to obtain more information as to the

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[3]Hudson B. Drake, "Major DOD Procurements at War with Reality," Harvard Business Review, January-February, 1970, p. 127.

feasibility of the project design. The goal is to clearly delimit the military requirement and to identify the best alternative method for accomplishing it.[4] For those programs which seem to hold promise an objective emerges which will provide a basic developmental strategy for the future. The phase can be from one to five years duration.

Contract definition.--Information gained from the concept formulation segment is applied. Two or more contractors are selected to competitively define the developmental effort. The emphasis is on planning. Each contractor must execute a preliminary program design, evaluate technical and schedule objectives, outline in detail the development and production program, and extrapolate the program costs. Such a painstaking routine is expected to reveal the risks and uncertainties inherent in the program.[5] Both the concept formulation and the contract definition phases can be classified as preacquisition segments, as related to the integration of the component parts into one or several weapon systems. An evaluation of the phase results can result in a decision to proceed. This period is of approximately six months duration.

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[4]Blue Ribbon Defense Panel, Report to the President and the Secretary of Defense on the Department of Defense, Appendix E, Staff Report on Major Weapon Systems Acquisition Process (Washington D.C.: Department of Defense, July, 1970), p. 1.

[5]Richard M. Anderson, "Anguish in the Defense Industry," Harvard Business Review, November-December, 1969, p. 166.

Engineering development.--The decision to develop an item for operational use leads to this phase. The specifications are more rigorously refined. The full-scale system will be developed and tested. The phase precedes production and is crucial for validating the design of the weapon system and may cover from two to four years.

Production and operation.--The weapon system has become a reality. The component units have been successfully integrated, and the decision has been made to produce the item. As the weapon systems come off the assembly line, personnel are trained in their use, and the systems are placed in the operational inventory. Though not considered in this study, support and maintenance are the next steps. The weapon system is operational until new technology stimulates modifications or the development of a different weapon. The cycle then is repeated.

Historical Perspective[6]

Two factors characterized the weapons acquisition process in Colonial times. These factors were generality and simplicity. The weapons technology was based on a society where men used weapons daily for gleaning a livelihood. Manufacturers and merchants could easily adapt to military production of items, such as rifles, hunting knives, and gun powder. Thus, weapons were general in nature and low cost

[6] Logistics Management Institute, op. cit., pp. 39-78.

production was possible. Also weapons were simple. The warship from a definitional standpoint was the most complex weapon which can be designated as a system. From a production reference point, weapons were produced by both private and public concerns. Competition existed between private companies as related to the selling of arms to the government and between private and public concerns. This situation existed in principle until World War I. The Industrial Revolution had set in motion technological forces which had been applied in a fragmentary fashion to local conflicts. World War I consolidated the various scientific advances. The result was the increasing use of weapon systems, such as the airplane, submarine, and tank. The trend was toward greater complexity and specialization. The successful application of many scientific advances to weapons development led to increased expenditures which resulted in more technical breakthroughs.

The United States entered World War II at a technological disadvantage. Technical advances had occurred but were introduced primarily into the commercial area during the interwar period. Instead of merely trying to cope with the technical advances of the enemy, the country forged ahead. The tendency of weapons development to press the limits of existing knowledge was accentuated. Many new weapon systems were placed in the operational inventory. The atomic bomb and the proximity fuse were created. Advances were made in

information technology. Increased complexity and specialization resulted in changes in the governmental organization structure. The Department of Defense was reorganized. A defense industry came into being in this technical and uncertain environment.

In the decade of the 1950's a technological revolution occurred. Systems, such as the Semi-Automic Ground Environment (SAGE), M-48 tank, the F-4 Phantom II fighter, were developed. They were created in response to a continuing external threat to the country.

This threat resulted in the acceptance of a large standing military force in a constant state of readiness. In order to provide the weapon systems needed, a permanent defense industry came into existence. From a historical standpoint the weapons acquisition process evolved from a rather simple process effected in a simplistic environment to a complex procedure which has to be conducted in a highly structured milieu. The military products evolved from general ones used by the majority to complex ones used only by a minority. The products are used in small quantities and must be manufactured by specialized firms which practice market segmentation and product specialization.

The Procurement Cycle

At each interface between a procurement phase a contract or contracts will be negotiated. Each contract has a life cycle commonly referred to as the procurement cycle. In

Figure 3 this cycle for an unsolicited sole-source procurement is outlined.

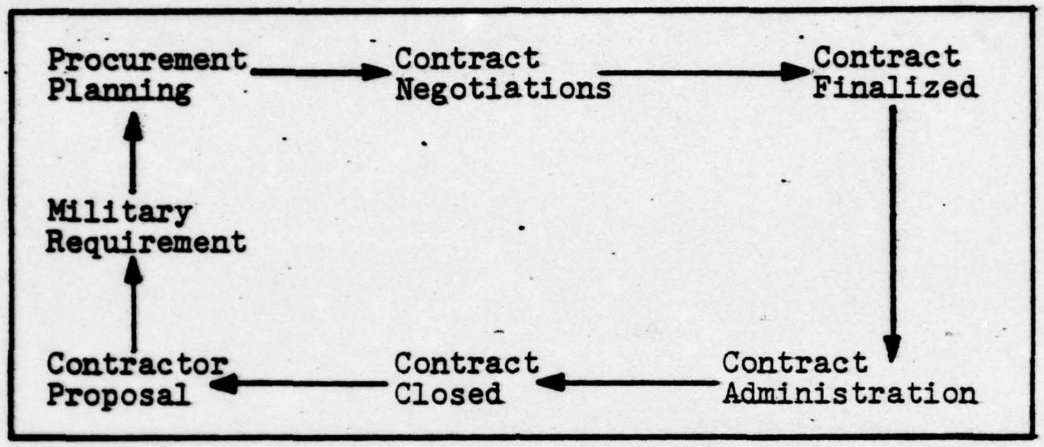

Fig. 3.--Contract life cycle

Contractor proposal.--The prospective contractor recognizes the need for a certain weapon component. Seizing this opportunity, a proposal is prepared which outlines the technical program to be pursued. A cost budget is prepared. The cost budget indicates the total costs to be incurred in conducting the program. At this point the budgetary figures are estimates. Only the passage of time can truly refute or validate them. The proposal is submitted to a government organization which has primary interest in the contemplated technical area. An assumption is made that the proposal is submitted to an Air Force agency which funds development projects.

Requirement validation.--After receipt the Air Force organization will evaluate the proposal from a technical and

cost standpoint. At this juncture the technical merits of the program are of paramount importance. Assuming the proposed developmental effort meshes with an Air Force requirement, the program will be approved for funding. Internal documents are prepared and the procurement section of the organization will be requested to negotiate a contract to support the developmental endeavor. The actual process is more complicated, but is being abstracted for simplicity.

Procurement planning.--This point in the procurement life cycle is critical. Multiple complex variables must be definitively evaluated. Cost, delivery dates, and quality must be established. The study deals primarily with the cost element and will, thus, hold the other two prime factors constant. The contract specifications have a significant effect as related to the probability of a cost growth. These specifications must be accurately evaluated on a cost basis. The cost-evaluation problem will be explored in greater detail in a section devoted to cost analysis. From a static standpoint, this part of the procurement cycle will be one of the critical aspects of the contemplated model.

Contract negotiations.--The process can be characterized as a bilateral monopoly market situation.[7] Assuming a sole-source procurement, the firm is a monopolistic seller. The government buyer is the only one interested in buying and

[7]Hibdon, op. cit., p. 267.

is, therefore, a monopsonistic buyer. This relationship is important and its implications will be explored. During the negotiation process a multiplicity of variables and relationships are examined and agreement reached. Among the variables are contract price, type of contract, delivery dates, and product quality. A contract price is an aggregate of estimates comprised of manhours, materials required, equipment needed, and other cost items. Should a significant variance occur in any one of the estimates, a contract cost growth may occur. Thus, the negotiation procedure is an important aspect of cost control.

Contract finalization.--This step involves statutory reviews by the procuring agency of the negotiated arrangement. A contract which reflects the negotiation agreements is written and sent to the contractor for analysis and signature. After the contractor signs the document, the government contracting officer is in a position to review the contractor's exceptions, if any, and then to sign the document also. The contract is now a legally binding agreement which basically requires that a given product be produced in a given quantity with a specific quality and that delivery be made at a designated time. The stipulated price also envisions delivery to a definite geographical location. The product may range from a hardware item to a paper report.

Contract administration.--Most contracts are assigned to either the specific service for research and development

contracts, or to the Contract Administration Services (CAS) in the case of production contracts for administration. Contract administration includes the production, inspection and delivery of the product (whether report or hardware item) to the purchasing activity or its designated representative. The procurement planning and negotiation phase may consume from one to twelve months. The administration period may cover several years. Many variables must interact in a predetermined manner to produce a product and to deliver it. Should one of these elements go out of control, cost variances can occur.

Contract closure.--After the production items have been delivered and accepted by the government, final payment is made. The contract is now completed and may be retired to the inactive file.

Summation.--On an over-all basis, a contract may span a time period of several years' duration. (See Figure 4.) Dollars are expended over time on line t_0T. The assumption of a uniform expenditure rate is made. At t_0 the contract is negotiated and a total price is determined. The future is uncertain and unknown. As a result of any number of circumstances, costs may be higher than anticipated (line segment t_2S). The cost growth is represented by the segment RS. Proper feedback during administration will reveal the deviant elements of cost. Investigation can be initiated to ascertain

the causes. Thus, in Figure 4, the two primary aspects of the procurement cycle are brought into focus. First, cost growths occur over time during administration; and secondly, factors considered at t_0, when the contract was negotiated may cause variances from line t_0T. The implications and extension of this primitive model will be examined in Chapters IX and X.

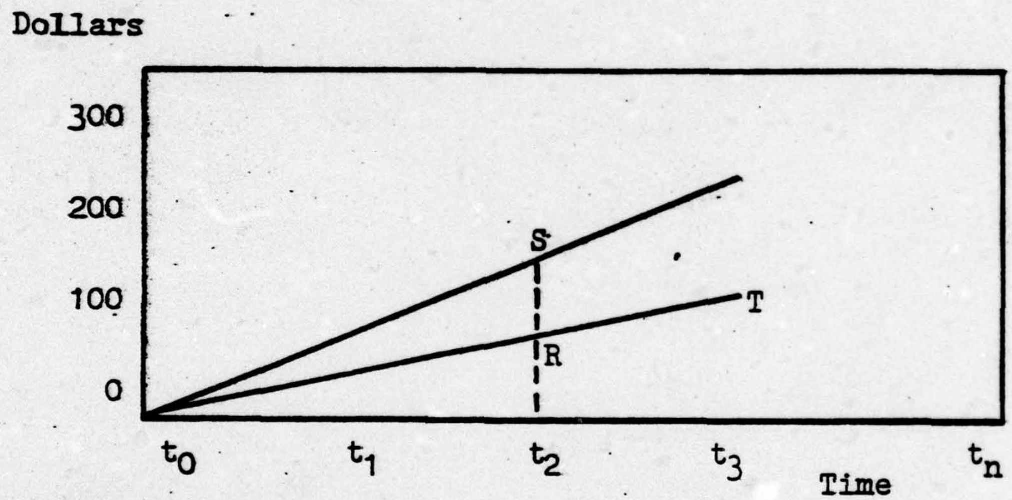

Fig. 4.--Contract expenditures

Cost Analysis

A distinction must be made between cost and price analysis.[8] The latter term refers to the evaluation of prices as proposed by a contractor. This procedure usually requires a comparison with past prices paid, catalogue list

[8]U.S., Department of the Air Force, Air University, Extension Course Institute, Procurement by Negotiation, Vol. 5, Course 6500, Procurement Officer (Amarillo Air Force Base, Texas: Air Training Command, 1 April 1971), pp. 60-62.

prices or other comparative techniques to determine whether or not a price is fair and reasonable to the government. Price analysis is applicable to fixed-price contracting of off-the-shelf hardware items. Cost analysis involves detailed analysis of the elements which are contained in a prospective contractor's cost proposal. This procedure is imperative for a sole-source, negotiated program where the specifications are relatively vague and nebulous. Cost categories, such as direct labor, direct materials, special test equipment, travel expense, and subcontracting would be evaluated as to fairness.[9] Evidence derived from independent studies by the Blue Ribbon Defense Panel supports the contention that an unwarranted degree of confidence is placed in cost estimates.[10] In many advanced development programs, where a goal, rather than a product, is being procured, cost prediction is difficult. When a contractor submits technical and cost proposals to a government activity, the contracting officer must ascertain the validity of the cost estimates. The contractor may have prepared the estimates by a comparison to a similar program. Previous estimates are increased by a certain percentage. Assuming a cost increase of 10 percent, an estimate

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[9]U.S., Department of the Air Force, Air Force Systems Command, Air Force Laboratory Procurement Management, AFSCP 70-3 (Washington, D.C.: Andrews Air Force Base, 30 June 1967), pp. 4-8 to 5-1.

[10]Blue Ribbon Defense Panel, Report to the President and the Secretary of Defense on the Department of Defense (Washington, D.C.: Department of Defense, 1 July 1970), pp. 83-84.

on a similar program of 100 dollars is transformed into a 110-dollar estimate for the new program.

Once these estimates are reduced to writing, they seem to assume an aura of infallibility. The fallacy of this posture stems from the uncertain nature of the future. The possibility of environmental change makes future cost variability almost inevitable.[11] The law of large numbers may permit the detailed estimates to offset one another to some extent. The occurrence of this condition is not certain. Thus, the decision-maker needs to insure that in the cost-analysis process every effort will be made to reduce the cost uncertainties inherent in a given research and development program.

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[11] W. Sutherland, Fundamentals of Cost Uncertainty Analysis (McLean, Virginia: Research Analysis Corporation, March, 1971), pp. 1-2.

CHAPTER IV

THE DEFENSE INDUSTRY ENVIRONMENT

The structure of the defense industry has evolved based on implosive inputs of a political, social, and economic nature. The continuing external threat, after World War II, led to the acceptance by the American public of a large standing military force and the growth of a specialized permanent defense industry. Several definitions have been applied to the defense industry. Kayloe concludes that the industry is composed of firms which produce the following items: aircraft, missiles, arms and ammunition, electronics, control and command equipment, and ships.[1] This definition relies on product characteristics. According to Peck and Scherer, the industry may be described in terms of product categories, economic roles, contractual arrangement, and by size.[2] An acceptable definition is that the defense industry is composed of those firms which sell products and

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[1] A. Kayloe, "Resource Allocation and Control in the Weapon Acquisition Process" (rough manuscript of book, Air Force Institute of Technology, 1970), p. 2.

[2] Peck and Scherer, op. cit., pp. 114-116.

services either directly or indirectly to the Department of Defense (DOD).

DOD-Contractor Relationship

Many of the political, social, and economic factors which have had a deterministic impact on the structure of the industry accrue from the relationship between the DOD and its contractors. Scherer indicates that this relationship is analogous to bilateral monopoly.[3] The relationship places the buyer in a monopsonistic position and the seller in a monopoly role. Berhold considers the government to be a monopsonist. However, he states that several contractors can generally provide a given product and thus, is a member of an oligopoly which can produce weapons to specification.[4] The large number of sole-source, negotiated procurements would seem to validate the bilateral monopoly relationship. However, at any given time other economic market classifications may well apply. This study will abstract from these exception-type situations.

Environmental Characteristics

Economic forces interact to create a relationship which sets the defense industry apart from the general

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[3]Scherer, op. cit., p. 156.

[4]Marvin H. Berhold, An Analysis of Contractual Incentives (Los Angeles, California: University of California, Los Angeles, Western Management Science Institute, September, 1967), p. 5.

business community.[5] Six basic interrelated factors comprise these forces:

(1) Absence of competition,

(2) Demand uncertainty,

(3) Geographical concentration,

(4) Production dependence,

(5) Industrial specialization, and

(6) External and internal uncertainty.

The high-dollar cost of developing weapon systems requires a firm which has a large working-capital base. The factor is not so pervasive, if only subsystem or component work is envisioned. In the systems concept formulation and contract definition phases two or more firms may bid on a program. As the project progresses into the system development phase, the unsuccessful firms are eliminated from competition.[6] This situation contributes to the cited sole-source-procurement methodology. An environment of no competition is enhanced by the fact that firms will specialize in a given research and development discipline to insure a constant demand for their products.

Demand uncertainty derives in part from the nature of the products which are needed by the government. Weapon systems and components are developed to fulfill a given

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[5]Peck and Scherer, op. cit., p. 17.

[6]Logistics Management Institute, DOD-Contractor Relationship--Preliminary Review (Washington, D.C.: Logistics Management Institute, March, 1970), p. A-2.

requirement created by an existing technological state-of-the-art. Continued research has a tendency to make such items obsolete. Weapons have a specialized use. Usually only a small number will be required. Another factor is the reality of budget limitations. Congress authorizes funds for the DOD. The military services in allotting funds to weapons investment projects are generally subject to funding constraints.

The primary defense contractors subcontract many component parts to small business firms. Transportation and other factors lead to a concentration of activity in the defense industry. The study by Peck and Scherer indicated that ten states led by New York, Michigan, and Ohio accounted for 70.6 percent of the total contract awards for the period 1959-1960.[7] Two factors are of interest. During the 1960 period the geographical concentration for defense work began to change. Congressional action was initiated directing the procuring agencies to spread the business among the different geographic areas of the country.[8] Also a trend toward geographical decentralization by industry has been detected.[9] These two factors might impinge on the future costs of weapon components and systems.

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[7]Peck and Scherer, op. cit., p. 111.

[8]Ibid., p. 113.

[9]James A. Constantin, Principles of Logistics Management (New York: Appleton-Century-Crofts, 1966), pp. 517-533.

According to the Harvard Business Review, 22,000 prime contractors, and 100,000 subcontractors participate in the defense industry.[10] This condition leads to a situation where numerous subsystems are being developed simultaneously.[11] A given subsystem delivers its products to another subsystem which eventually inputs to the major system. Substantial risk is involved, as a failure in any subsystem can disrupt the production process and result in increased costs. Such a relationship creates a network of firms which are dependent on the government and one another for business. In this web-like structure price accretion occurs, as the subcontractors pass their costs on to the next higher tier until the final component cost is charged against the prime contract. Unless adequate cost control is exercised, a cost growth for the prime contract can occur. Production dependence contributes to the concentration of defense dollars in a relatively small group of companies. In fiscal year 1968, five firms had prime contracts for military business in excess of one billion dollars each.[12] The firms were McDonnell Douglas Corporation, General Electric Company, and United Aircraft Corporation. In fiscal year 1969, four of

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[10]Jack Raymond, "Growing Threat of Our Military-Industrial Complex," Harvard Business Review, May-June, 1968, p. 57.

[11]Aerospace Research Center, Aerospace Profits vs. Risks (Washington, D.C.: Aerospace Industries Association of America, Inc., June, 1971), p. 3.

[12]Kayloe, op. cit., p. 29.

the companies repeated this achievement.[13] United Aircraft Corporation fell to .997 billion dollars of defense business. Thus, large defense contractors with much financial and political clout negotiate with the government in a bilateral monopoly-market situation.

The final environmental factor is the uncertainty inherent in the research and development spectrum. Glennan considers uncertainty to be the dominant environmental characteristic and posits a dichotomous classification.[14] The two groups are internal and external. The frame of reference is the individual system or project. Factors, such as the future nature and objectives of military forces, the effectiveness of these forces, and alternative ways to obtain the objectives, are classified as external uncertainties. For example, a given state-of-the-art may dictate that a certain weapon system be developed. Scientific advancements occur. New technology induces a state of obsolescence for the initial system or subsystem. The Snark and Navaho cruise missiles illustrate the point.[15] Demand uncertainty was treated separately and is a manifestation of an external variable. Internal uncertainties interact with the external ones in a

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[13] "Who Pulled in the Big Ones," Business Week, November 8, 1969, p. 130.

[14] T. K. Glennan, Jr., "Research and Development," in Defense Management, ed. by Stephen Enke (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1967), p. 276.

[15] Ibid., p. 277.

stimulus-response relationship. Internal uncertainties comprise the second class. These uncertainties include factors such as technical design difficulties, component integration, and financial stability of the company.

The environmental characteristics have been considered separately, when in fact they interact directly with one another. The situation exists in terms of industrial specialization. The DOD has a specialized demand for unique highly complex weapon components and systems. A highly specialized industry has evolved to supply the needed goods and services.

The political and social elements relate to the legal restrictions placed on the industry by the legislative and the judicial branches of the government.[16] First, the firm dealing with the Federal Government is contracting with a sovereign power. The courts have often favored the government as a contracting party. An example is the governmental immunity from suit except when it has consented to be sued. Secondly, certain statutory clauses are required in contracts, such as Buy American, Davis-Bacon, and Walsh-Healy. These clauses have a special economic or social goal in mind. Implementation and adherence can cost the firm more than on a contract for commercial work. This fact follows from the

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[16]Procurement and Finance Council, Risk Elements in Government Contracting (Washington, D.C.: Aerospace Industries Association of America, Inc., October, 1970), pp. 1-3.

extra paperwork generated, if from nothing else. Thirdly, the Congress has agencies, such as the General Accounting Office which investigate the procurement practices of the DOD and report to Congress and indirectly to the American public. Therefore, defense business is conducted under the scrutiny of the Congress and the public. Finally, the legislative branch of the government appropriates the funds for the DOD and other government agencies. A reduced funding level following a year of large expenditures may well result in overcapacity in the defense industry. The interrelated nature of the firms will cause a reduction to be felt throughout the industry and the country. The reduction will spread with a multiplier effect, eliminating jobs and idling equipment and facilities. The characteristics considered in this Chapter either result from the nature of uncertainties or from the efforts that are taken to cope with them. A better understanding of the uncertainty parameter is required.

CHAPTER V

THE MEASUREMENT OF RISK AND UNCERTAINTY

From a simplistic frame of reference, uncertainty is the absence of information. For decision-making purposes, when all information about the future is known, there is no reason for a wrong decision. The uncertainty spectrum is illustrated in Figure 5. A decision maker may be located at any point on the spectral continuum. Problem definition moves the individual to the left of the spectrum toward complete knowledge or certainty.

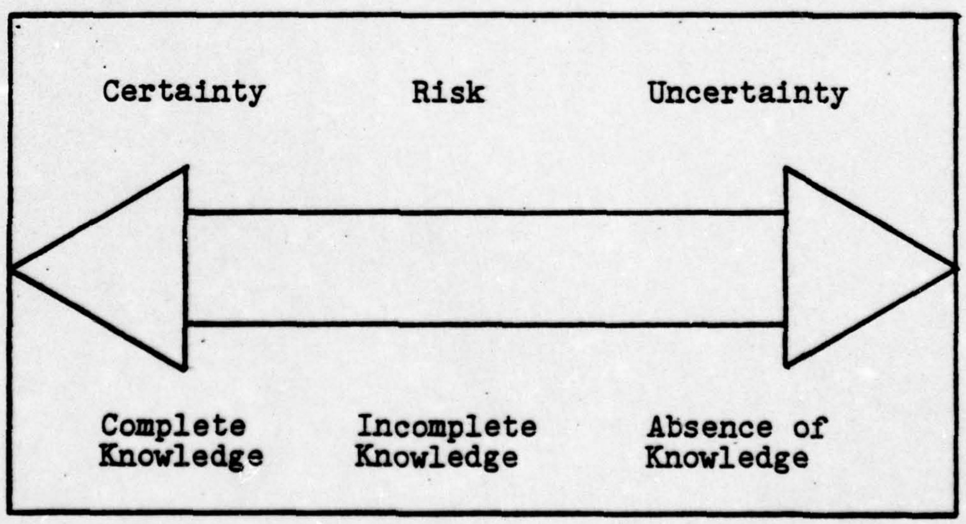

Fig. 5.--The uncertainty spectrum

The assumption is made that uncertainty and risk can be treated as synonomous terms. A review of the uncertainty spectrum confirms the difference between the terms as one of degree. Decision makers usually have some information to serve as a basis for decision making. Seldom will a decision be made when no information is available. Rather the decision will be delayed, and action initiated to obtain some information. Risk implies that the probability of future events is known in terms of a probability distribution.[1] Uncertainty generally is defined as a situation where the probability of events is not known. From a subjective standpoint, the decision maker usually has intuitive feelings about the future and is able to structure a probability distribution. This subjective estimation of probabilities will move the decision maker into the risk segment of the spectrum. A careful definition of the problem in terms of past ones of a similar nature will assist in enhancing the visibility of subconsciously submerged information. Chance,[2] Grayson,[3]

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[1]Frank H. Knight, Risk, Uncertainty and Profit (New York: Houghton Mifflin Company, 1921), pp. 19-21.

[2]William A. Chance, Statistical Methods for Decision Making (Homewood, Illinois: Richard D. Irwin, Inc., 1969), p. 3.

[3]C. Jackson Grayson, Jr., "The Use of Statistical Techniques in Capital Budgeting," in Financial Research and Management Decisions, ed. by Alexander A. Robichek (New York: John Wiley & Sons, Inc., 1967), pp. 90-91.

Bierman and Smidt,[4] Robichek and Myers,[5] and Lerner and Carleton[6] support this assumption. Knight maintains that the two concepts should be treated as separate entities.[7] Hunt supports him.[8] Hunt's assertion is based on Dean's treatment of the concepts.[9] Dean defines the terms and treats them separately. Hwang in his studies takes this same approach.[10] The latter three individuals concentrate their efforts in the risk part of the uncertainty spectrum. The approach taken by both groups to cope with the unpredictability of the future, however, from a conceptual standpoint is basically the same. Therefore, uncertainty will be equated with risk, since the terms are essentially indistinguishable.

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[4]Harold Bierman, Jr. and Seymour Smidt, The Capital Budgeting Decision (2nd ed.; New York: The MacMillan Company, 1967), p. 196.

[5]Alexander A. Robichek and Stewart C. Myers, Optimal Financing Decisions (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965), pp. 68-69.

[6]Eugene M. Lerner and Willard T. Carleton, A Theory of Financial Analysis (New York: Harcourt, Brace & World, Inc., 1966), pp. 99-101.

[7]Knight, op. cit., pp. 19-21.

[8]Raymond G. Hunt, personal letter, July 8, 1971.

[9]Joel Dean, Managerial Economics (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1951), pp. 7-8.

[10]John D. Hwang, Analysis of Risk for the Materiel Acquisition Process, Part 1: Fundamentals (Rock Island, Illinois: Systems Analysis Directorate, U.S. Army Weapons Command, November, 1970), pp. 9-17.

Taxonomic Considerations

Various terms have been used in the literature to categorize and describe the types of uncertainties which have been identified and observed. In Table 1 these terms have been classified into four taxonomic classes: environmental, functional, informational, and technical. The purpose of these classes is to elaborate a definitional structure for reference purposes.

In a footnote, Peck and Scherer indicate that uncertainty from a technical standpoint has no utility for their study.[11] Yet, if the uncertainty in a situation is to be dealt with, the gap between the colloquial meaning of the term and its technical meaning must be bridged. Uncertainty has significance when related to the future. Changes in the external or internal environment for a given organization will occur in the future. Since the future cannot be predicted, it is uncertain and in the face of unknown variables, a decision made in the present may well turn out to be wrong. Therefore, from a generic category, the merging of the environmental, informational, and technical taxonomic classes is necessary. The functional class is another way of describing the informational class of variables. The relationships from a definitional and sequential standpoint are illustrated in Figure 6.

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[11]Peck and Scherer, op. cit., p. 18.

TABLE 1

UNCERTAINTY TAXONOMY

Description	Comment
Environmental:	
1a. Nature[a]	1a. The uncertainty is related to natural factors, such as storms and floods.
b. Social and Political	b. The term relates to the impossibility of being able to predict with any precision the actions of social and political groups.
c. Communication Media	c. The disparities that exist in the access which people have to the various informational media. The differences result in ignorance on the part of many groups and individuals.
d. Time	d. The passage of time results in changes which can distort the results of decisions based on a past state-of-affairs.
2a. External[b]	2a. These uncertainties relate to factors external to a project which can impinge on final results.
b. Internal	b. Internal uncertainties comprise those stemming from the technical approach taken, etc.
3a. Exogenous	3a. The stimulus, initiating a given change, comes from outside the organization.
b. Endogenous	b. The stimulus, initiating the change originates within the organization.

TABLE 1--Continued

Description	Comment
Functional:	
1a. Business Risk[c]	1a. The firm is uncertain about its future income stream. The risk is associated with the firm's operation.
b. Financial Risk[d]	b. The uncertainty is generated by the ratio of debt to equity in the capital structure. The amount of earnings available to common stockholders. For contracting the risk of profit or loss on an individual contract is involved.
c. Technological Uncertainty[e]	c. Changes in the state-of-the-art can render a weapon obsolete. Thus, uncertainty exists as to how long a weapon can remain in the operational inventory.
d. Production[f]	d. Most products represent an integration of component parts. Should a part not be available, then the finished product cannot be ready on time and even its cost can be affected.
Informational:	
1a. Anticipated Unknowns[g]	1a. The unknowns in this class are those that a contractor is aware of. The problem area is anticipated.
b. Unanticipated Unknowns	b. These unknowns cannot be foreseen.
2a. Known Unknowns[h]	2a. The facts the contractor knows that he does not know.
b. Unknown Unknowns	b. The unknowns the contractor does not anticipate.

TABLE 1--Continued

Description	Comment
Technical:	
1a. Uncertainty	1a. The known is completely dominated by the unknown. The probability distributions for future events are not known.
b. Risk[i]	b. A decision leads to one of a specific number of well defined alternatives. The totality of outcomes for a given variable can be described by a probability distribution.
c. Certainty	c. Each decision leads to a predictable outcome. No doubt as to the final outcome is possible.
2a. Subjective[j]	2a. The term relates to the probabilities assigned to an event and which are wholly based on the observation choice.
b. Objective	b. These probabilities are derived by specific procedures independent of the problem being confronted.

[a]Charles O. Hardy, Risk and Risk Bearing (Chicago, Illinois: The University of Chicago Press, 1923), pp. 2-3.

[b]Peck and Scherer, op. cit., pp. 17-54.

[c]James C. Van Horne, Financial Management and Policy (Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1968), p. 145.

[d]Herman O. Stekler, The Structure and Performance of the Aerospace Industry (Berkeley, California: University of California Press, 1965), p. 84.

[e]Peck and Scherer, op. cit., pp. 45-48.

[f]J. Robert Lindsay and Arnold W. Sametz, Financial Management (Homewood, Illinois: Richard D. Irwin, Inc., 1967), p. 53.

TABLE 1--Continued

[g]Drake, op. cit., p. 124.

[h]Frank Burnham, "Plotting the Unks-Unks," Armed Forces Management, February, 1970, p. 55.

[i]Frank H. Knight, Risk, Uncertainty and Profit (New York: Houghton Mifflin Company, 1921), pp. 19-21.

[j]D. J. White, Decision Theory (Chicago, Illinois: Aldine Publishing Company, 1969), p. 53.

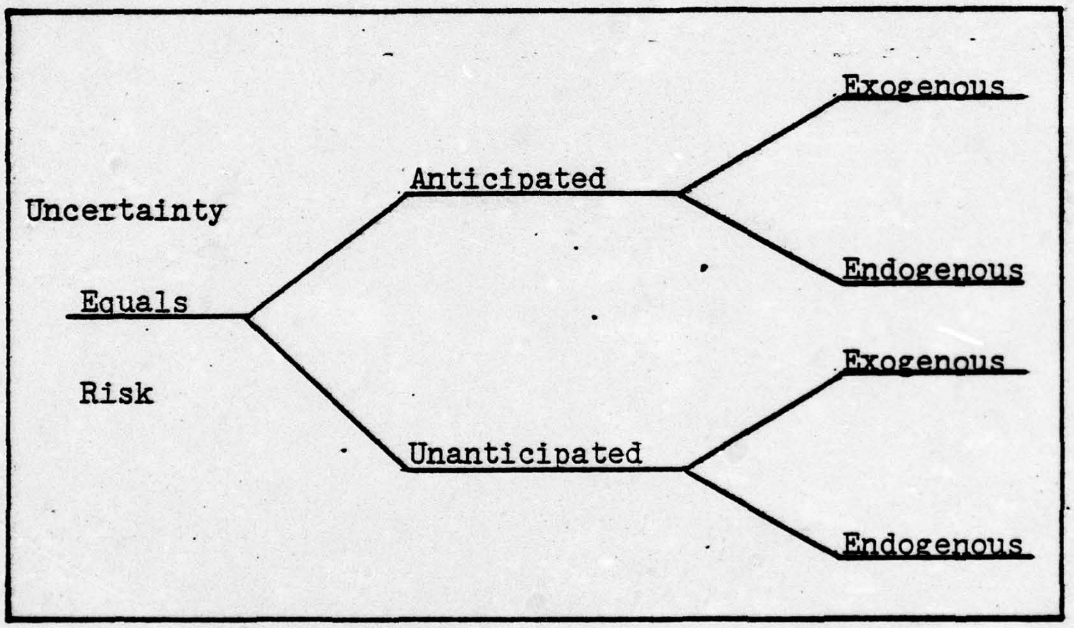

Fig. 6.--Definitional tree for uncertainty

These classes will permit a common language as related to uncertainty. For example, anticipated exogenous uncertainty in a situation is a variable which is external to the organization. The decision maker envisages a possible impact on the future outcome of a decision. Unanticipated exogenous variables are external to the organization and unknown to the decision maker.

In relation to the weapons acquisition process, uncertainty is resolved over time. As a scientific concept traverses the spectrum from research through exploratory development to production, information is gleaned from each stage which permits the successful solution for the emergent problems. In the concept formulation and contract definition phases the anticipated unknowns (exogenous and endogenous) are dominant. In the area of engineering development, the unanticipated (exogenous and endogenous) prevail. The uncertainty related to the concept being considered decreases at a uniform rate. This assumption will facilitate the exposition. (See Figure 7.) One of the goals of risk analysis is to increase the slope of the uncertainty function.

Informational Considerations

In a theoretical context, information is difficult to define. In a generic sense, information is what an individual knows and also what he does not know. The sum is the total pool of knowledge. Information is rarely complete when a decision is to be made. Rather, additional information is sought so that the uncertainty in the situation may be reduced.

Information may be thought of as a commodity.[12] In this sense, information can be stripped of its intangible

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[12] G. L. S. Shackle, Uncertainty in Economics and Other Reflections (London: Cambridge at the University Press, 1955), pp. 9-10.

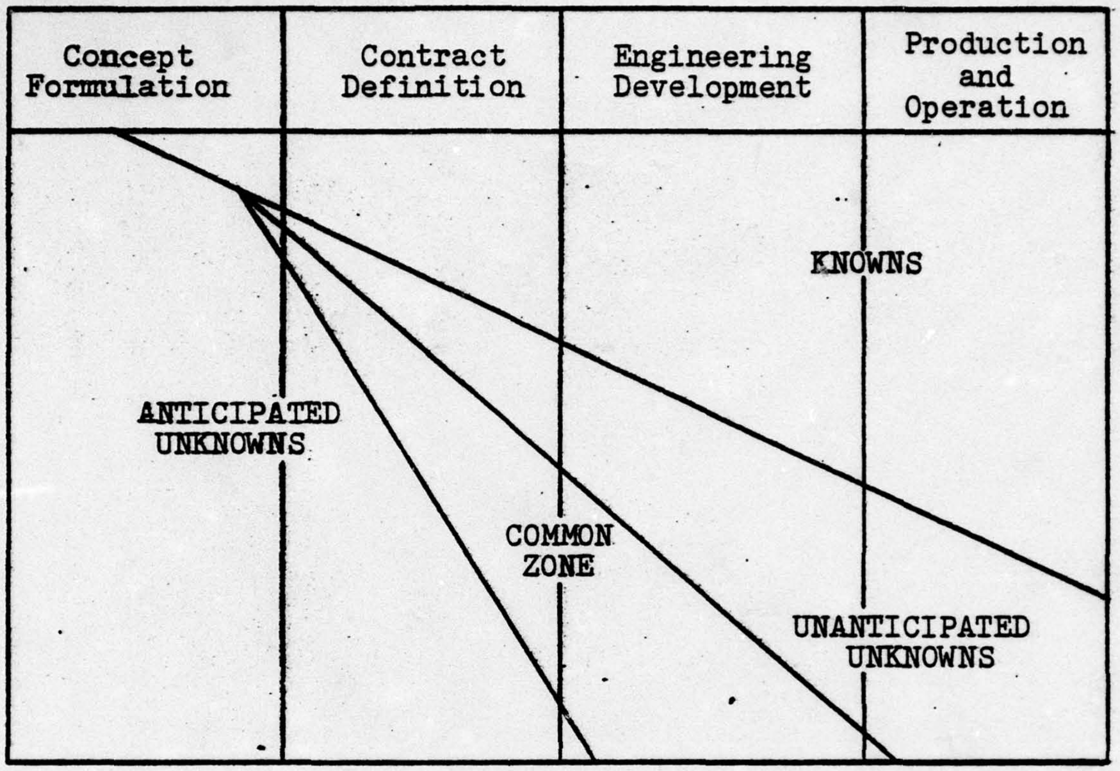

Fig. 7.—The resolution of unknowns

Source: Hudson B. Drake, "Major DOD Procurements at War with Reality," Harvard Business Review (January-February, 1970), pp. 129-131.

aura and treated as a tangible item which may exhibit varying degrees of value in terms of supply and demand. For an organization or individual information will thus exist in the internal and external environments of the firm. In the absence of perfect knowledge about the characteristics of a system, the decision maker will assume a position on the uncertainty spectrum between the two poles of uncertainty and certainty. Movement toward certainty and, perhaps,

ultimate survival, can occur by the acquisition, use, retention, and transmission of information.[13]

Information Characteristics

As a commodity, information possesses several characteristics. These factors can be described and measured. This statement is especially appropriate if information is considered the input commodity for a management information system. The information system will exist for the purpose of obtaining feedback about the state of an organization or the financial status of expenditures under a development contract. This feedback ideally will exhibit certain characteristics.[14]

Objectivity.--The goal is to eliminate bias or to recognize predispositions which might structure the information in the direction of a preconceived result. Information, as such, is usually neutral. If the data are objective, the receiver of the input signal will provide any observed bias.

Validity.--An information system is designed to acquire certain relevant data elements. Feedback information must reflect this pattern.

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[13] Norbert Wiener, Cybernetics (2nd ed.; Cambridge, Massachusetts: The M.I.T. Press, 1961), p. 161.

[14] Robert W. Swanson, An Introduction to Business Data Processing and Computer Programming (Belmont, California: Dickenson Publishing Company, Inc., 1967), p. 190.

Reliability.--The information transmitted to the decision maker must be free of error. Control mechanisms will be necessary to maintain integrity in the system.

Relevance.--The quest is for the information to relate to the crucial decision variables in the system. A review of minutia or trivial information might be interesting but serves no purpose and possesses no utility for decision making.

Completeness.--The acquisition of relevant data will permit the resolution of uncertainty in such a manner that suboptimal decisions can be avoided.

Usefulness.--The economics of a process require that the information be of a type which can be used for decision-making purposes. Extraneous data has a definite opportunity cost. In economic terms, the marginal return from the information must exceed, or be equal, to the marginal cost of obtaining the data.

Organization.--Information in a specific system or universe may exhibit varying degrees of organization. Entropy constitutes the amount of disorder in a system.[15] In general, the amount of entropy tends to increase over time. The need is to reverse the flow. A source of negative

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[15]Ira G. Wilson and Marthann E. Wilson, Information, Computers, and System Design (New York: John Wiley & Sons, Inc., 1967), p. 257.

entropy is necessary. Information is obtained from this negentropy.

Recency.--Closely related to the organization factor is the ~~requirement that the information~~ in a system be updated. The tendency of the entropy in the system to increase causes a degradation of existing information.

Uncertainty-Time Relationship

The degree of uncertainty present in a situation increases in direct proportion to the number of unknowns involved and the distance into the future of the contemplated events. Thus, uncertainty is a direct function of time. The more distant the event relative to the present, the more uncertain is its outcome. The basis for the uncertainty is the absence of information concerning changes which will occur.

Change is a constant in the environment. Change is predicated on the nature of time. Fluidity and movement characterize time.[16] Movement is a dynamic concept and is meaningless without a frame of reference. Time is measured by the rotation of the earth as related to the sun and its solar system movements. Certain characteristics can be delimited for time.[17] These characteristics are duration, tempo, sequence, chronicity, and familiarity. Duration

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[16] Robert Sommer, "A Time for Every Purpose," Natural History, August-September, 1971, p. 24.

[17] Loc. cit.

describes a time segment as circumscribed by a specific reference point. A day has a duration of 24 hours but is meaningful only in relation to the earth's rotation. Tempo relates to the rate of passage. Tempo will be consistent for any given reference point but changes from point to point. Various courses of action with different sequences of events are possible. The occurrence of certain events may require the later occurrence of other dependent events. Some sequences are comprised of independent events. Chronicity depends on the time pattern of sampling entries into a system. Several brief entries will provide a different perspective than one prolonged survey. Familiarity relates to the informational cognition variable. The level of awareness varies from no knowledge to perfect knowledge. From a biological context, an organism has the opportunity to increase its knowledge level dependent on innate ability to detect a pattern of change.

The goal is the reduction and resolution of uncertainty over time. From the vantage point of the decision maker at t_0 (see Figure 8), uncertainty increases at a constant rate on line t_0T. This relationship can be expressed by the formula:

$$U = bt$$

where U represents uncertainty, b is the slope of line t_0T (b is assumed to be a constant), and t is the variable, relating to the number of time periods, as movement on the

time continuum is contemplated. However, regarding the time perspective of t_0, the time frame is static. The passage of time involves movement as information is gained from the environmental sensors in the form of feedback. Uncertainty is reduced by lowering line Rt_n.

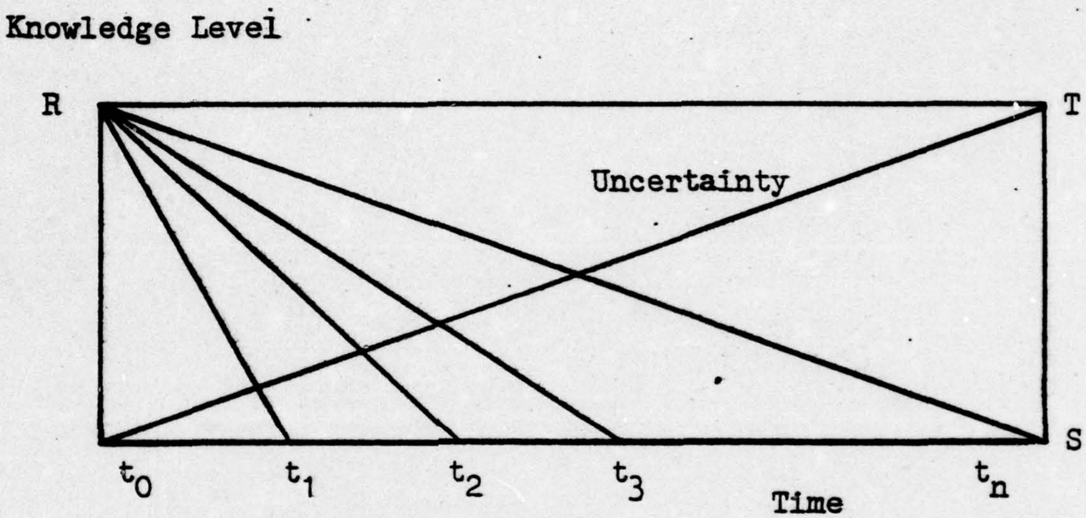

Fig. 8.--Uncertainty-time relationship

Uncertainty Elimination

In Figure 8, uncertainty is completely resolved at time t_n. The future has become the present. The decision made at time t_0 can be evaluated as to its degree of error. However, such an ex post analysis is good only from a historical standpoint. The goal is dichotomous. First, for the discussion applicable to time t_0, the decision maker needs techniques to improve the quality of current decisions. This fact relates to the static time frame. Secondly, informational sampling on a discrete time-interval basis is

required to permit the decision maker to modify his past decisions. These actions will assure that the outcome at t_3 or t_n is of the proper quality. The sequential acquisition of new information permits evaluation and control.

Uncertainty can be eliminated either by taking definite action to reduce it or by transferring the risk to others.[18] Thus, in the government-contracting relationship, uncertainty can be transferred to the contractor or the risk may be shared and action taken by both parties to reduce its magnitude.

Individual action.--The methods for elimination or reduction of risk on a generic level can be summarized as follows:

(1) Prevention of the harmful events. An extremely risky part of the program is eliminated.

(2) Research to remove uncertainty. Additional data is captured to permit better problem definition which in turn leads to better solutions.

(3) Offsetting of risks. A portfolio of investments is combined in such a manner that the less risky investments tend to dampen the oscillations caused by the more riskier projects.

(4) Accumulation of reserves. Contingency funds are accumulated to meet unexpected needs. In contracting, supplemental funds are added to a program. The goal is to

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[18]Hardy, op. cit., p. 10.

anticipate the occurrence of unexpected problems. If nothing happens, the funds are recouped. However, an opportunity cost is incurred.

(5) Combination or aggregation of risks. The law of large numbers applies. The aggregation of individual elements absorbs the fluctuations of the individual members. While the behavior of one unit may be relatively uncertain, the behavior of the whole may be predictable within certain limits.[19]

Risk transfer.--The transfer of risk is important, as it relates to the proportion borne by the commercial contractor. Various sharing ratios may be negotiated, and with this arrangement both parties will be interested in techniques to reduce the magnitude of the risk which they face. If the government bears all of the risk, then the contractor must be willing to accept a lower profit. Therefore, for theoretical purposes the assumption will be made that the two parties are going to share the risks. The exact proportion is indeterminate until negotiations are completed.

Risk Measurement

As Professor Hunt asserts, risk is difficult to measure from a conceptual standpoint.[20] Uncertainty was defined as the absence of information. In most cases decision makers

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[19] Ibid., pp. 11-31.

[20] Hunt, op. cit., p. 1.

have some information available. As postulated, information can be considered a commodity. It can be described and measured. In most decision situations, a range of events and values is possible.[21] From this starting point two measures of uncertainty can be used. First, probability may be used as a measure of uncertainty.[22] Then, the probability distribution for a given random variable can be used to derive probabilities that a certain value will occur.[23] The expected value and the distribution of values around it may be used to predict the probability of a given event. (See Table 2.)

TABLE 2

COMPUTATION OF EXPECTED VALUE

Forecast	Estimated Cost	Probability	Expected Value
Best Estimate	$40,000	.4	$16,000
Next Best	60,000	.4	24,000
Least Best	85,000	.2	17,000
		1.0	$57,000

[21] Sutherland, op. cit., p. 6.

[22] Samuel A. Schmitt, Measuring Uncertainty (Reading, Massachusetts: Addison-Wesley Publishing Company, 1969), pp. 2-4.

[23] Van Horne, op. cit., p. 71.

The standard deviation for the distribution in Table 2 is approximately \$16,640. The value may be used to determine the probability of a cost less than \$50,000.[24] This probability is calculated to be .34.

Thus, probability may be used as measure of uncertainty. In the classical sense, probability may be applied when an event can occur in N ways and if N_p of these outcomes have an attribute p then the probability of N_p is equal to:

$$P(N_p) = \frac{N_p}{N} .$$

The procedures that will be used in this study will be governed by the axioms and theorems of Frisz for the probability calculus.[25] For example, the sum of the probabilities for mutually exclusive and equally likely alternatives of a contemplated event must equal one.

Several useful techniques employ the "subjective" concept of probability.[26] The Bayesian approach is based primarily on the principle of degree of belief and on the concept of conditional probability. Bayes' formula will be used to compute posterior probabilities when necessary.

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[24]Herbert Arkin and Raymond R. Colton, Tables for Statisticians (New York: Barnes & Noble, Inc., 1950), p. 119.

[25]Gerhard Tintner, Methodology of Mathematical Economics and Econometrics (Chicago, Illinois: The University of Chicago Press, 1968), p. 57.

[26]Ibid., pp. 58-59.

Risk Preference Theory

Individuals exhibit varying attitudes toward risk.[27] An individual has different preferences for a risky versus a safe investment. Stock prices for a risky business usually are lower than those for sound business ventures where the financial risk is lower. Exceptions exist, for some people prefer investments with a high degree of risk and will bid prices up accordingly. Grayson postulates three classes of individuals relative to risk preference.[28]

Risk seekers.--These are individuals who like to live daringly. They seek high-risk investments, such as wildcat oil wells. The person is willing to incur losses in the hope that a big strike will more than compensate for past losses.

Risk averters.--Persons who seek only low or medium risk situations generally attempt to avert high-risk environments. They will buy U.S. savings bonds in lieu of a highly speculative mining stock. An assumption will relegate the majority of managers to this category.

Risk ignorers.--These people ignore the existence of risk, hoping that it will go away. For example, a member of

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[27]Ralph O. Swalm, "Utility Theory-Insights into Risk Taking," Harvard Business Review, November-December, 1966, pp. 129-134.

[28]Grayson, op. cit., pp. 91-92.

this elite group might be an individual in the days of the wild west who was willing to face Billy-the-Kid in a high-noon shootout.

Cardinal utility theory measures an individual's attitude toward risk. A group of lotteries in sequence is posed to derive the person's utility function.[29] The unit of measurement is the utile. A utility function for three different individuals has been plotted in Figure 9. Utiles are on the ordinate axis and dollars on the abscissa. In terms of the classes listed, A would represent a risk ignorer, line B a risk averter, and line C a risk seeker. Curve B displays decreasing risk aversion.[30] This fact means that the decision maker becomes less conservative as his asset position increases. According to Professor Hunt, studies of government-contractor personnel reveal them to be risk averters.[31] They would, therefore, possess curves which resemble curve B. Thus, the utility function is subjective and personal. No reason exists for expecting one individual's curve to conform to that of another. For the small business where one man makes the main decisions, a utility function may be derived. Decision rules can be formulated and authority delegated to subordinates relative to the scope of

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[29]Van Horne, op. cit., p. 83.

[30]John S. Hammond, III, "Better Decisions with Preference Theory," Harvard Business Review, November-December, 1967, p. 138.

[31]Hunt, op. cit., p. 1.

decisions which they can make based on the preferences of the respective executive.

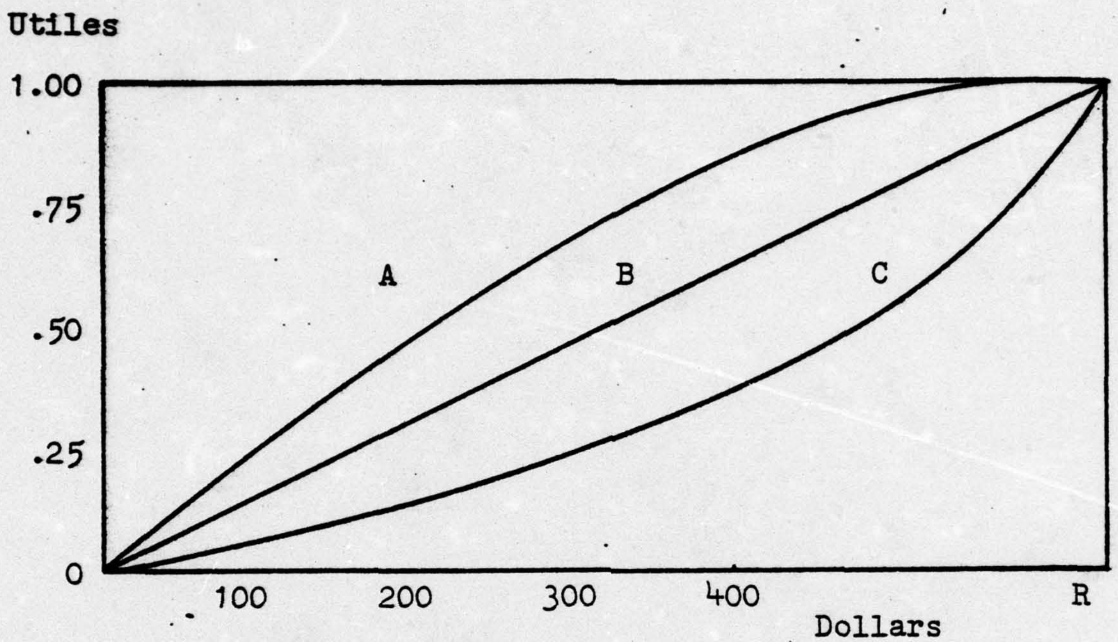

Fig. 9.--Three types of preference curves

Source: John S. Hammond, III, "Better Decisions with Preference Theory," Harvard Business Review (November-December, 1967), p. 138.

Individual utility theory has its bases in economic theory and is finding limited acceptance. However, the concept of a group utility function has not found as many advocates.[32] The addition of individual functions in order to derive a group function does not appear feasible. No common denominator has been posited. Two approaches have been suggested.[33] The usual approach to utility function derivation

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[32]Bierman and Smidt, op. cit., p. 289.

[33]Ibid., p. 289.

is followed. Instead of an individual giving the answers, an entire group responds to the lottery. Secondly, after a series of decisions have been made, the profile of the decision process is constructed and used to prepare a group utility function.

Cost Factors

The reduction and resolution of uncertainty over time can be expensive. The type of information system which will provide the highest quality data is the automated system. In practice, the semiautomated data system prevails. A central computer will direct the program to obtain data at periodic intervals. These data will reflect the status of a contractual program.

Two basic costs are apparent. The cost of acquiring the data with updates throughout the life of the system, and the initial cost of the hardware and its periodic maintenance. The situation may be likened to the model which displays the economic-order-quantity relationship for inventories. (See Figure 10). Curve A represents the increasing costs for more elaborate systems to obtain informational feedback. Curve B is the cost of acquiring and updating information for a range of systems. This cost decreases over size, since the larger systems are more automated, and therefore, give a lower unit cost based on higher efficiency. The total costs are finally reflected by curve C. At point X the lowest point on C and the intersection of A and B the lowest cost

system is determined. This point holds true only for the specific combination of variables under consideration. Information which cannot be used is not to be collected. When timely decisions are crucial, too much information can be detrimental. A saturation situation occurs. Time does not permit thorough analysis; consequently, hasty decisions are made or decisions are delayed. In a sense the decision-making process causes oscillations in the immediate activities of the organization. These oscillations are an organic type of instability. According to D. K. Stanley-Jones, stability in the sense of biological organisms is that of an oscillating, dynamic system.[34] In effect, the manager should receive only as much data as he can use.

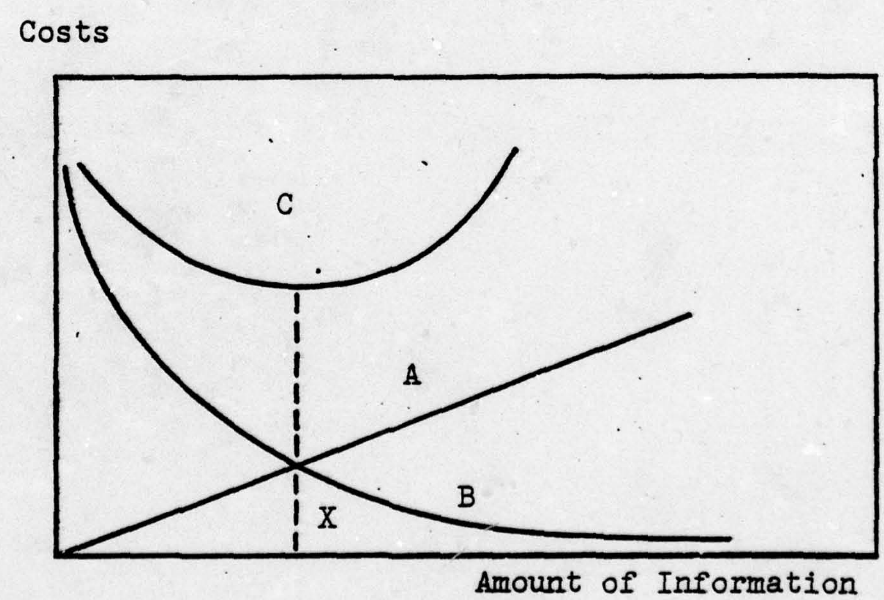

Fig. 10.--The optimal size information system

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[34]D. K. Stanley-Jones, The Kybernetics of Natural Systems (New York: Pergamon Press, 1960), p. 130.

The stability of the total feedback system is dependent on maintaining a balance between the amount of information in the system and the cost of maintaining its integrity. Another way of expressing the cost is in terms of the last increment for a given time period. The additional information possesses utility or it is not acquired. The marginal value received from the increment must be greater than, or equal to, the marginal cost of the data. For example, in warehouse location theory studies have shown that with 25 warehouses delivery service can be made to 90 percent of the market in one day.[35] Fifty warehouses give 96 percent coverage in one day and with 100 warehouses, 99 percent of the market can be covered in one day. According to distribution cost analysis, the optimal number of warehouses is 25. Seventy-five warehouses need to be added to obtain an increase of only 9 percent first-day coverage. Thus, the marginal value is less than the marginal cost. This type of cost is of the fixed variety which will be continuous once the capability is installed.[36] Thus, past some optimal point increments of information possess diminishing marginal utility. The uncertainty relative to a decision may be reduced by using techniques to better delineate the project and to provide information for a better decision. Control systems must be developed to monitor progress and to report

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[35]Constantin, op. cit., pp. 401-405.

[36]Hardy, op. cit., pp. 8-18.

deviations in a timely manner. The uncertainty cannot be completely eliminated. However, it can be reduced. The question is how much time and resources are the pertinent parties willing to pay for this uncertainty reduction.[37] As startling as it may seem, a cost growth for a specific contract may be less costly than the actions which would have to be taken to preclude its occurrence. This Chapter has abstracted from the government contractual environment. The treatment of risk in government contracts in conjunction with incentives will be the subject of the next Chapter.

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[37]DiBona, op. cit., p. 8.

CHAPTER VI

AN OVERVIEW OF CONTRACTUAL INCENTIVES

The military services have attempted to cope with uncertainty by the use of incentives and contractual arrangements. Degree of risk bearing by contractors has been a key determinant of the profit allowed on a particular contract. Theoretically, the more uncertainty borne by the contractor, the larger the profit permitted. A study by Seagle, though not conclusive, casts some doubt as to whether large profits do entice contractors to accept an extremely high degree of uncertainty.[1] Seagle's findings seem to indicate that contractor negotiators are risk averters. They are willing to accept a lower profit with a greater sharing of the risk between the two parties. The sharing of risk between the government and the contractor is reflected by the type of contract used to support developmental programs.

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[1]John P. Seagle, A Method for the Study of Risk Aversion from Incentive Contract Negotiations (Buffalo, New York: State University of New York, October, 1968), pp. 10-17.

Types of Contracts

The negotiations between the parties will eventually result in a contract to confirm the agreements which have been reached. The contract types available for this purpose range from the firm-fixed-price to the cost-plus-fixed-fee contract.[2] These two contract types represent the extremes of the contractual spectrum. Between the two poles are a variety of contract types that exhibit features of both. Each will be examined relative to four characteristics: (1) degree of risk-sharing, (2) profit opportunity, (3) cost estimate realism, and (4) control. This comparison is made in Table 3. The comments in the Table are advantages and disadvantages from the perspective of the contractor.[3] The contract types are divided into two groups: (1) fixed price, and (2) cost reimbursement.[4] Contractual instruments, such as time and materials contracts, letter contracts, basic agreements, and call procurement arrangements, though sometimes used in research and development, fall outside the purview of this study.[5]

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[2]Art, op. cit., p. 91.

[3]Drake, op. cit., pp. 132-134.

[4]Stekler, op. cit., pp. 78-84.

[5]U.S., Department of the Air Force, Air University, Extension Course Institute, Contract Considerations, Vol. 3, Course 6500, Procurement Officer (Amarillo Air Force Base, Texas: Air Training Command, 1 April 1971), pp. 6-8.

TABLE 3

COMPARISON OF CONTRACT TYPES

Type of Contract	Risk Sharing	Profit Opportunity	Cost Realism	Control
1. Fixed Price				
a. Firm-Fixed-Price (FFP)	Contractor bears total risk	High potential for profit	Incentive is to reduce cost	Control is minimal by government
b. Fixed-Price-Escalation	Risk is shared	Mixed profit potential	Costs subject to revision	Government monitors contingency provisions
c. Fixed-Price-Redeterminable (FPR)	Reduces the contractor's risk	Profit potential is reduced	Less incentive to reduce costs	Increased government control
d. Fixed-Price-Incentive-Fee (Costs Only) (FPIF)	Higher risk for contractor	No ceiling on profit	Cost efficiency is encouraged	Less government control
e. Fixed-Price-Multiple-Incentive	Risk is shared	Potential for profit is mixed	May increase costs	Complex administration

TABLE 3--Continued

Type of Contract	Risk Sharing	Profit Opportunity	Cost Realism	Control
2. Cost Contracts				
a. Cost-Reimbursement (CR)	Contractor risk is minimized	None	No motive to reduce cost	Increased government control
b. Cost-Sharing Contract (CS)	Risk is shared	None	Motivation for cost control	Mutual control
c. Cost-Plus-Incentive-Fee (CPIF)	Contractor has limited risk	Reduced fee due to lower risks	Motive for reduced costs	Increased government control
d. Cost-Plus-Multiple-Incentives	Risk is shared	Profit determination is delayed	Costs increase is shared	Complex administration
e. Cost-Plus-Fixed-Fee (CPFF)	Government bears the maximum risk	Lower fees because of reduced risk	Low motivation for cost efficiency	Maximum government control

Source: Hudson B. Drake, "Major DOD Procurements at War With Reality," Harvard Business Review (January-February, 1970), pp. 132-134.

The descriptive terms in Table 3 use the FFP contract as a frame of reference. The firm-fixed-price (FFP), fixed-price-redeterminable (FPR), fixed-price-incentive-fee (FPIF), cost reimbursement (CR), cost-plus-incentive-fee (CPIF), and the cost-plus-fixed-fee (CPFF) contracts will be considered in greater detail.

Firm-fixed-price contract.--The FFP contract is the most primitive of the contract types.[6] A specific good or service is purchased for a fixed price. The negotiated price is a ceiling. Price is not to be adjusted. The price ceiling precludes this measure. This type of contract is suited for those cases where exact and firm specifications exist. Often in development the item purchased is a goal and not an object.[7] The research and development program profile contains both exogenous and endogenous uncertainties. The FFP contract makes little provision for the possible uncertainties from the standpoint of the contractor. The contractor risk is at a maximum. Accordingly, the potential for profit is high. The contractor, therefore, has a stimulus to exercise cost control. In general, regulations require that the FFP contract will be used unless another contract type is more

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[6]Department of Defense, Proceedings of the 1967 DOD-Wide Procurement Pricing Conference (Hershey, Pennsylvania: Government Printing Office, 1967), p. 98.

[7]Ibid., p. 98.

appropriate.[8] In the past, public policy has preferred this contract.[9] Specifically, the FFP contract is mainly appropriate where performance has been demonstrated and cost uncertainties are deemed to be almost nonexistent.[10] (See Figure 11.) The sharing arrangement governs the method whereby the government and contractors agree to share costs. For example, under the FFP contract the ratio is 0/100 which means that the contractor bears 100 percent of the difference between actual and estimated cost; the government defrays none. The inverse relationship between profit and cost is shown in Figure 11. In the case of zero profit, a cost of $220 is experienced. If a price of $220 was initially negotiated for the contract, this amount would include costs of $210 and profit of $10. However, a cost growth of $10 has occurred under the contract. The cost growth has essentially consumed the contractor's profit of $10. Under the FFP contract the government does not share the cost growth.

Fixed-price-redeterminable contract.--The FPR contract is seldom utilized by the government. Some individuals

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[8] Stekler, op. cit., p. 78.

[9] Logistics Management Institute, Briefings on Defense Procurement Policy and Weapon Systems Acquisition (Washington, D.C.: Logistics Management Institute, December, 1969), p. 4.

[10] Department of Defense/National Aeronautics and Space Administration, Incentive Contracting Guide (Washington, D.C.: Government Printing Office, October, 1969), p. 5.

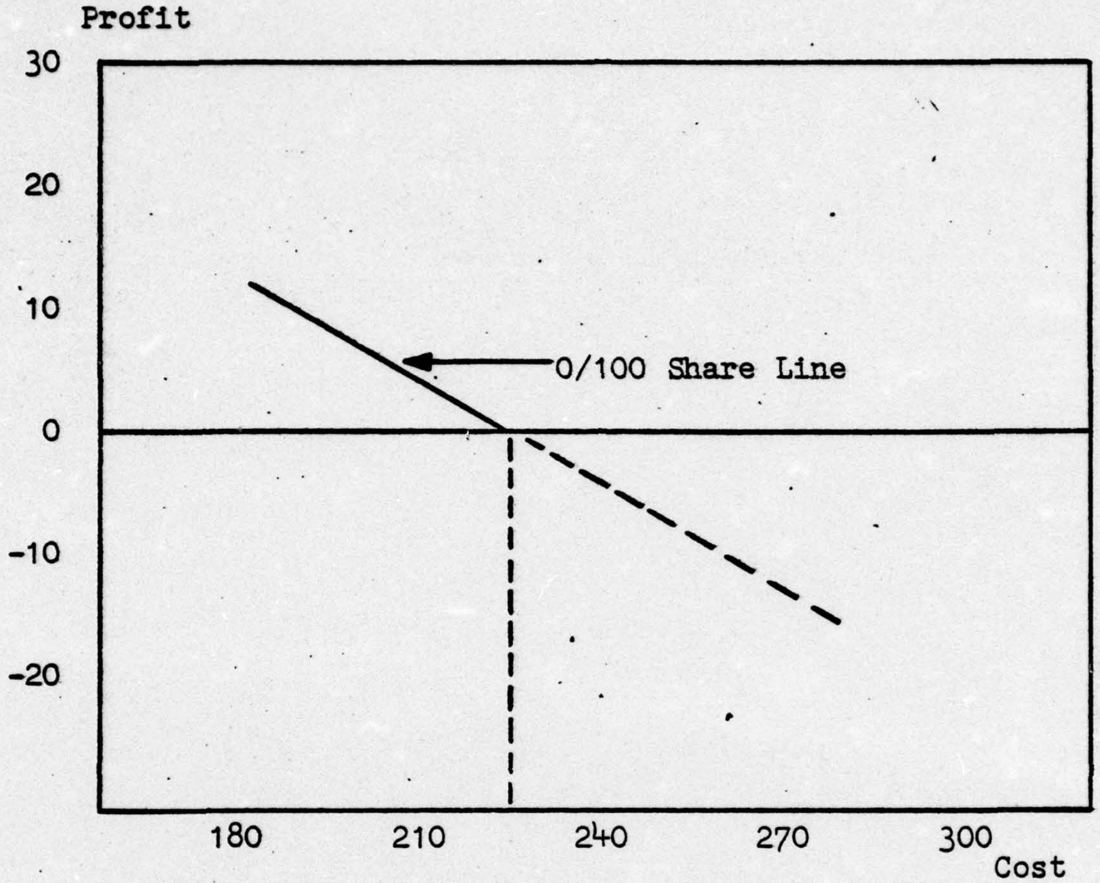

Fig. 11.--Sharing arrangement for FFP contract

Source: Department of Defense/National Aeronautics and Space Administration, Incentive Contracting Guide (Washington, D.C.: Government Printing Office, October, 1969), p. 23.

have charged that it represents a form of the cost-plus-a-percentage-of-cost contract which is illegal under the terms of the Armed Services Procurement Regulations (ASPR).[11] The claim is that since the contract is subject to redetermination at periodic intervals the contractor is encouraged to incur unnecessary costs. The validity of such a charge for

[11] Stekler, op. cit., p. 80.

a given contract would seemingly depend on the adequacy of cost visibility and control. Under this arrangement the contractor and the government share the program uncertainties. This contract type is not used often.

Fixed-price-incentive-fee contract.--The FPIF contract with firm target is comprised of the target cost, target profit, target price, share arrangement, and price ceiling. Assuming that the terms listed in Table 4 are negotiated, a hypothetical situation may be examined.

TABLE 4

TERMS FOR A FPIF CONTRACT

Contract Components	Negotiated Terms
Target Cost	$100,000
Target Profit	10,000
Target Price.	110,000
Price Ceiling	120,000
Share Arrangement	50/50

In the event of a cost growth, the contract price will not exceed $120,000. Assuming a cost growth of $40,000, the government will share 50 percent of the cost increase. The target cost of $100,000 plus the government's share of the cost growth will bring the total program cost to $120,000 which represents the price ceiling on the contract. The purpose of this contract is to provide the contractor with

an incentive for reducing costs. The cost reductions are shared and the contractor's share is added to his profit. The contractor's risk under this contract is less than under the FFP and FPR types. The FPIF contract is profiled in Figure 12.

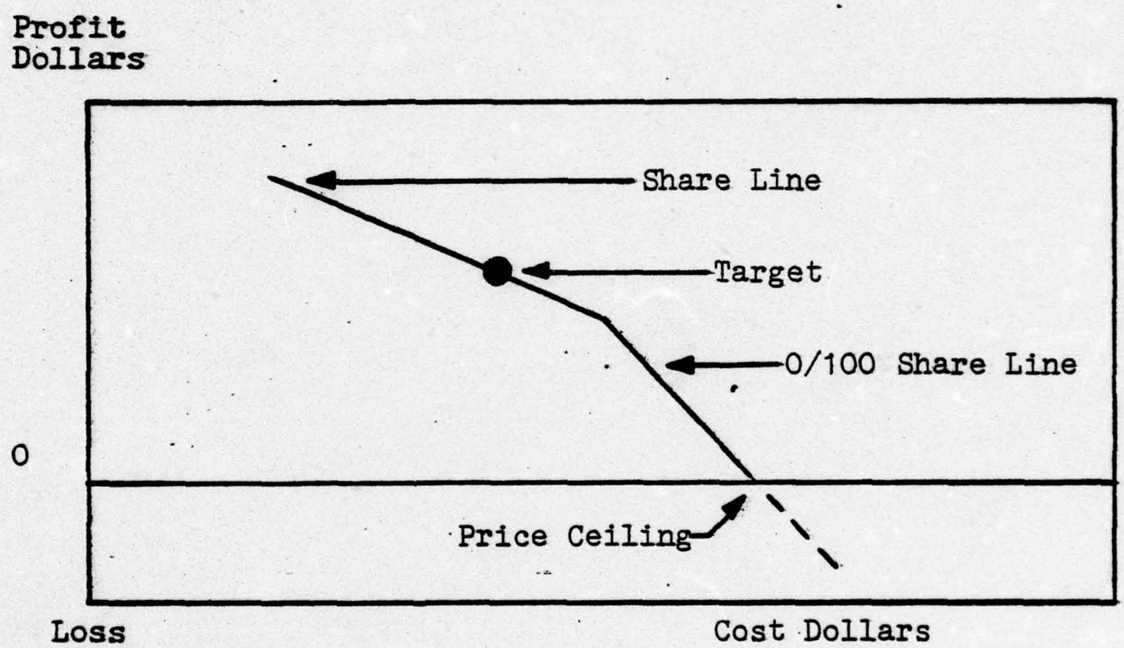

Fig. 12.--Sharing arrangement FPIF contract

Source: Department of Defense/National Aeronautics and Space Administration, Incentive Contracting Guide (Washington, D.C.: Government Printing Office, (October, 1969), p. 24.

Cost reimbursement.--This contract type is suitable for those instances where the work is not sufficiently defined. Research conducted by educational and other nonprofit institutions is usually supported by means of the cost contract. An estimated cost is negotiated. The cost is tentative as a consequence of the vague work statement.

The final cost may be higher or lower than the negotiated cost. The contractor is required by contractual provision to give the government advance notice should a cost growth be anticipated. The terms of the contract are very similar to the terms of the CPFF contract except that all references to a fee are inapplicable.[12]

Cost-plus-incentive-fee contract.--This type of contract is very similar to the CR type except that a fee is permitted. Consequently, CPIF contracts are used to support programs with commercial firms. The main features are a target cost, target fee, maximum fee, minimum fee, and the share ratio. The cost uncertainties are such that a FFP contract is not appropriate, but are not so great as to justify the use of a CPFF contract.[13] Three features distinguish the CPIF contract from the FPIF contract.[14] First, the CPIF contract has no price ceiling. Allowable costs for a program are governed by the ASPR, Section XV. Finally, under the CPIF contract the maximum fee permitted is fixed by the ASPR. The situation for the CPIF contract is illustrated by Figure 13. Profit in Figure 13 is at a maximum value to point A. If costs increase beyond this position, then profit

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[12]U.S., Department of the Air Force, Air Force Systems Command, Air Force Research and Development Contracting Officer's Handbook, AFSCP 70-2 (Washington, D.C.: Andrews Air Force Base, 30 June 1967), p. 4-4.

[13]Incentive Contracting Guide, op. cit., p. 33.

[14]Ibid., p. 33.

decreases until point B, where it levels out. Therefore, increased costs penalize profit potential.

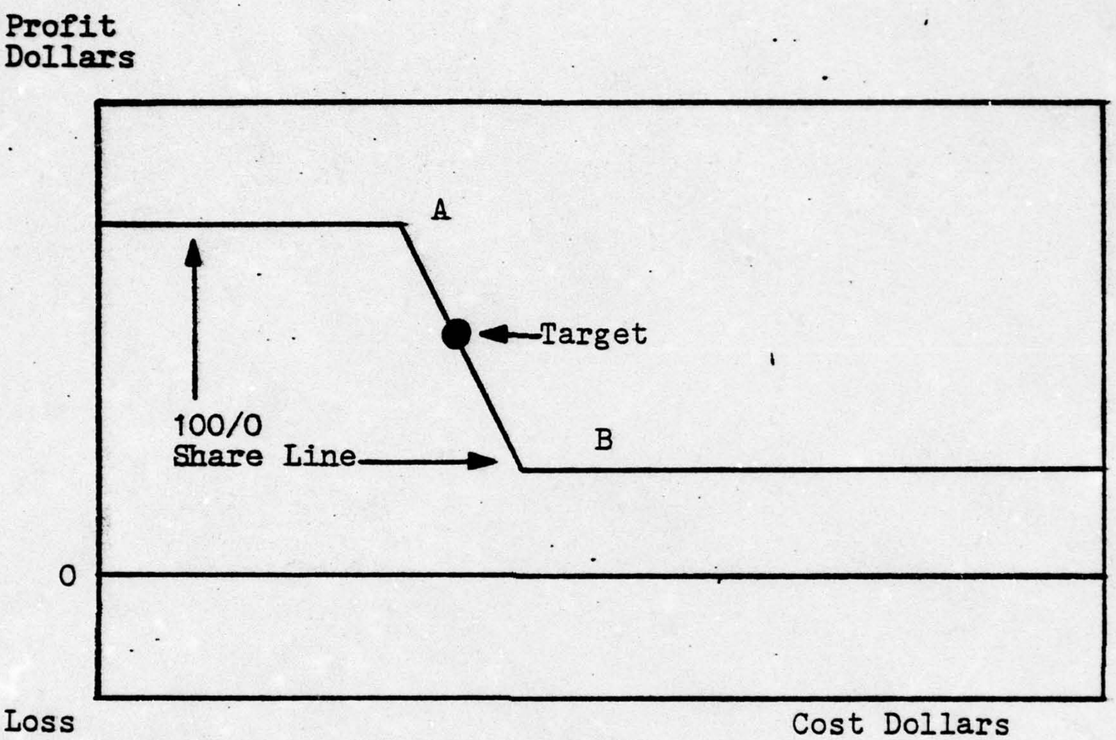

Fig. 13.--Sharing arrangement for CPIF contract

Source: Department of Defense/National Aeronautics and Space Administration, Incentive Contracting Guide (Washington, D.C.: Government Printing Office, October, 1969), p. 34.

Cost-plus-a-fixed-fee contract.--The CPFF contract is designed for use in research, exploratory development, and advanced development. In these areas of the spectrum, the level of contract effort is often unknown. A fee is allowed to compensate the contractor for the risks borne. However, fee is generally lower than the one permitted under the other types of contracts. This situation accrues from

the fact that the share ratio for the CPFF contract is 100/0. (See Figure 14.)

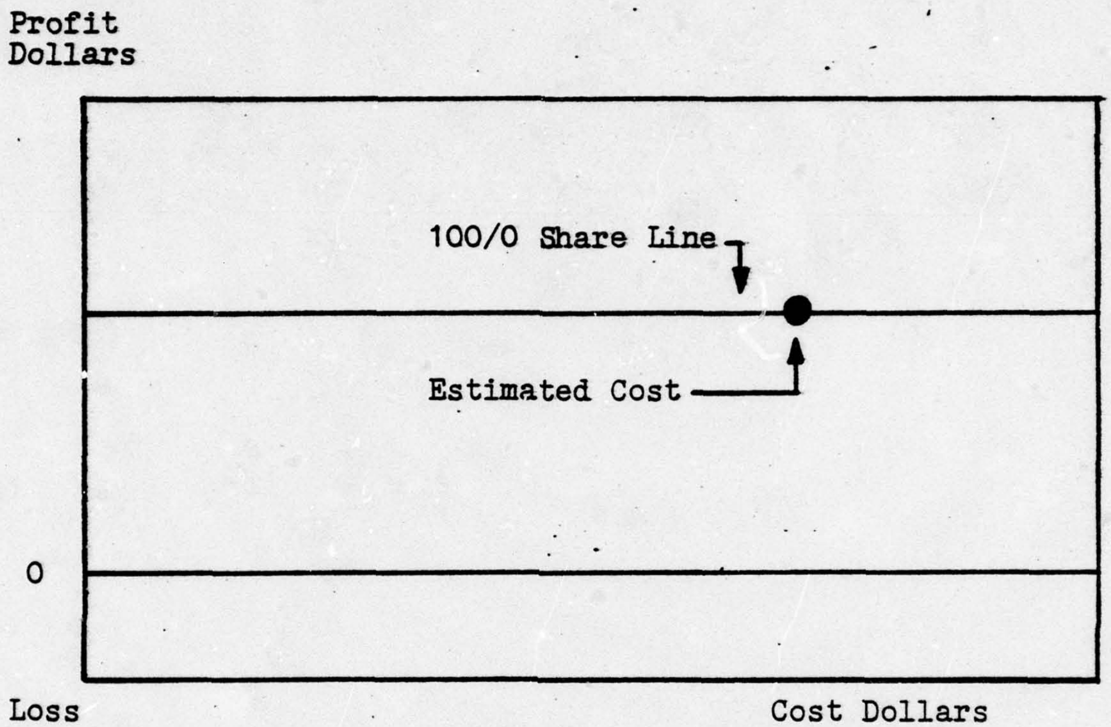

Fig. 14.--Sharing arrangement for CPFF contract

Source: Department of Defense/National Aeronautics and Space Administration, Incentive Contracting Guide (Washington, D.C.: Government Printing Office, October, 1969), p. 38..

Fixed cost contract (FCC).--The FCC contract has been used on a limited basis. The contractual format is a mixture of the FFP and CR contracts.[15] The idea is to contract on a fixed-price basis for those cost elements which are relatively certain and to use cost reimbursement

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[15]Thomas E. Bahan, "Fixed Cost Contracts," NCMA News Letter Anthology, Vol. No. 1, 1968-1969-1970 (Inglewood, California: National Contract Management Association, June, 1970), p. 64.

provisions for the uncertain elements. An estimated cost is negotiated. After the period of performance is completed, the cost reimbursement provisions are audited and a final price is determined.

Cost-plus-award-fee contract (CPAF).--The contract fits into the contractual spectrum between the CPFF and CPIF contract. DOD and NASA have used this type since 1962.[16] The key requirement is to determine the fee which will be paid at specific intervals. The fee awarded is based on the quality of the contractor's work. The determination is subjective and can be appealed by the contractor. The CPAF contract components are a base fee, a maximum fee, provision for a variable award fee, estimated cost, and a fee payment plan.

Profit Considerations

In a free-enterprise economy, profit maximization is considered to be the goal of the individual firm. Profit is a payment to a factor of production and represents a reward for risk taking. This facet of profit is germane to government contracting. Above average risk taking must be rewarded by above average profits. The relationship is a direct one. The profit motive is then the primary incentive for stimulating contractors to exercise cost control.

For a FFP contract, profit is computed as follows:

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[16] Incentive Contracting Guide, op. cit., p. 245.

$$\Pi_A = P - C_A$$

where Π_A stands for actual profits, P for contract price, and C_A for actual contract costs. The relationship between costs and profit is an inverse one. If C_A is reduced to a lower level, then profits will increase. If costs go out of control, profit may be eliminated. A loss will be experienced if C_A is greater than P.

The situation for incentive contracts is more complex. The objective is to motivate the contractor to reduce costs by allowing him to share the actual savings. The contractor's share of the savings is added to profit. An incentive contract model illustrates these relationships:

$$\Pi_A = \Pi_T + b\ (C_T - C_A)$$

where Π_A stands for actual profits, Π_T for target profits, C_T for target costs, C_A for actual costs, and b is the contractor's share of the savings.[17] If no savings are experienced, the last expression becomes zero, and actual profit is equal to target profit. Should actual costs exceed target costs then the formula indicates a reduction of profit. Let

$$E = C_T - C_A$$

then, when $C_T > C_A$, E is positive and if $C_A > C_T$ then E is negative. For the situation where $C_A > C_T$:

Frederick T. Moore, "Incentive Contracts," in <u>Defense Management</u>, ed. by Stephen Enke (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1967), p. 216.

$$\Pi_A = \Pi_T - E$$

From this formulation, it would seem that profits can only be increased by minimizing contract cost.

One factor influencing the size of realized profit, if costs are controlled, is b, the sharing ratio.[18] In his study, Fisher assumes that the sharing ratio provides a measure of financial risk. As pointed out in Table 3, incentive contracts require the contractor to bear a larger degree of risk than would be necessary under a CPFF contract. However, with a high profit reward for cost control, the expectation is that incentive contracts might give a high percentage of underruns. Fisher's study revealed that CPFF contracts had an average contract cost growth rate of 17.8 percent, while all but one group of incentive contracts reflected underruns. An average underrun of 3.6 percent was computed for contracts with sharing rates between 0.15 and 0.25. He questions the validity of the data since sole-source contractors can inflate target costs, creating a bias toward underruns. This bias results from the absence of competition. Essentially, no way exists to distinguish between the "bias effect" and the "incentive effect."[19]

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[18] Irving N. Fisher, Cost Incentives and Contract Outcomes: An Empirical Analysis (Santa Monica, California: The RAND Corporation, September, 1966), p. 29.

[19] Ibid., p. 35.

Profit Methodology

For a FFP contract, profit has been defined as the difference between price and actual costs. Thus, profit is a residual, and from an accounting reference point, this statement is adequate. However, for efficient resource utilization alternate uses must be at least acknowledged. The firm must produce those goods which maximize profits. Highly-dispersed profit distributions in an industry reflect the high level of risk present.[20] In a study by Cootner and Holland, the hypothesis of a positive association between business risk and rate of return was tested.[21] A linear model was developed, using data from 39 industries for the entire postwar period through 1960. They found that a one percent increase in dispersion was coupled with an approximately one percent increase in average industry rate of return. Also, 30 percent of the variability of the industry rate of return was explained by the variation of individual firm rates of return. This variability of returns emphasizes the probability that losses, as well as profits, can occur. Should firms consistently take high risks and not be rewarded, then they will either exit the industry or go out of business.

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[20]Gordon R. Conrad and Irving H. Plotkin, "Risk/Return: U.S. Industry Pattern," Harvard Business Review, March-April, 1968, p. 91.

[21]Paul H. Cootner and Daniel M. Holland, "Rate of Return and Business Risk," The Bell Journal of Economics and Management Science (Fall, 1970), pp. 214-217.

Numerous departures could result in a detrimental loss of productive capacity in individual technical areas.

The sole-source procurement abstracts from the competitive environment. Price for a contract is a negotiated variable which, when permissible, will include a profit. The ASPR for years required profit to be a subjective aggregation based on a cursory evaluation of the effect of competition, the degree of contractor risk, the complexity of the work contemplated, the extent of government cost assistance, the contractor's past performance record, and the soundness of the individual cost estimates that were proposed.[22] A disparity developed between the theory and the working-level application of the instructions. As a result, profit is often historical in nature computed as a percentage of estimated contract costs.

Profit objectives.--For the government the profit policy objective is to provide the contractor with an opportunity to earn a fair and reasonable profit.[23] Fair and reasonable has meaning only within the framework of the environmental factors which exist for a given procurement. In the bilateral monopoly market arrangement, the exact price resulting from negotiations cannot be determined in advance.[24]

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[22] Air Force Research and Development Contracting Officers' Handbook, op. cit., pp. 4-26.

[23] Incentive Contracting Guide, op. cit., p. 59.

[24] Hibdon, op. cit., pp. 267-269.

The price will be predicated on the skill and power of the participants and is indeterminant within certain limits. Profit for a developmental contract cannot reasonably be expected to conform to an average figure. The final figure must be based on an analysis of the unique combination of factors for the program being negotiated.

Weighted guidelines.[25]--To enhance the attainment of the fair and reasonable goal a weighted-guidelines method for determining profit is used. The procedure is a fairly mechanical algorithm which is used to establish a profit goal. The application of some judgment is required. Factors, such as contractor's input to total performance, assumption of uncertainty, and previous performance are included.[26] The final negotiated amount may differ considerably from the goal, as agreement on the underlying analytical details of applying the weighted guidelines is not mandatory.[27]

Profit Patterns

Assuming risk aversion on the part of the defense firm, the number willing to enter into a highly risky

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[25] Air Force Research and Development Contracting Officers' Handbook, op. cit., pp. 4-27.

[26] Stuart J. Evans, Harold J. Margulis, and Harry B. Yoshpe, Procurement (Washington, D.C.: Industrial College of the Armed Forces, 1968), p. 118.

[27] Air Force Research and Development Contracting Officers' Handbook, op. cit., pp. 4-27.

industry would be small.[28] Those that respond would do so in anticipation of being rewarded with a high rate of return.

Controversy has existed over the actual level and trend of profits for defense contractors. The Logistics Management Institute (LMI) in a study released in 1970 reported that the contractors' average pre-tax profits were 12.8 percent for defense work, 19.5 percent for nondefense durable-goods manufacturers, and 16.3 percent for commercial work by defense contractors.[29] The base for these percentages was total sales. The report by LMI stated that over a ten-year period defense profits had consistently ranged below those of commercial durable-goods companies. Critics of this study insisted the results were unaudited and biased by the industry sample. A study by the General Accounting Office (GAO) indicated profit averaged 6.5 percent measured as a percentage of sales, 28.3 percent as a return on total capital investment, and 56.1 percent as a return on equity capital.[30] The period covered by the GAO study was 1966 through 1969. A broader sampling by GAO cited the percentages as ranging from 3.9 to 5.4 percent on sales, 10.2 to 14.7 on total capital invested, and 19.8 to 28.4 percent on equity capital investment. On the basis of profits as a percentage

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[28] Hardy, op. cit., p. 40.

[29] "Fuel for the Fires on Defense Profits," Business Week, April 11, 1970, p. 30.

[30] "The Profit Puzzle in Procurement," Business Week, March 6, 1971, p. 44.

of sales, adjusted for methodology, the GAO results do not appear to differ significantly from the LMI findings.[31] Reduced profits by defense firms have led to a flight of capital from the industry.[32] The significant factor is considered to be a government policy of shifting risk from the government to the industry without commensurate increases in negotiated profits. According to press releases during June, 1971, the profit rate on defense contracts is expected to increase.[33]

Profit Renegotiation[34]

The purpose of this process is to eliminate "excessive profits." The Renegotiation Act is administered based on the contractor's profits for an entire fiscal year and not on an individual contract basis. The Act is enforced by the Renegotiation Board. The reviews are applicable, if a contractor signs a contract subject to renegotiation, and his total business activity is in excess of one

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[31] *Ibid.*, pp. 44-45.

[32] F. Trowbridge Vom Baur, "Shifting the Risk to Government Contractors and the Flight of Capital," *NCMA News Letter Anthology*, Vol. No. 1, 1968-1969-1970 (Inglewood, California: National Contract Management Association, June, 1970), p. 23.

[33] "Defense Profits to Rise," *The Norman (Okla.) Transcript*, June 1, 1971, p. 3.

[34] U.S., Department of the Air Force, Headquarters, U.S. Air Force, *Procurement Law*, AFM 110-9 (Washington, D.C.: Special Activities Group, Office of the Judge Advocate General, USAF, 31 December 1970), pp. 8-17 to 8-18.

million dollars. The process is subjective and the decision of the Renegotiation Board is based on an evaluation of the facts surrounding each case.

CHAPTER VII

THE COST GROWTH PROBLEM

The current term for a cost overrun is the one which has been used in this study, namely, cost growth. The difference in terms is related to timing and control.[1] A cost overrun implies that contract funds have been expended, and therefore, the program did go out of control. From a technical frame of reference, cost growth covers this case, as well as the situation where unanticipated costs are envisioned for the future. In the latter case, however, the costs can be controlled through actions, such as program modification or curtailment. The term will be used to refer to those situations where a cost overage has been or will be experienced.

Costs for a FFP contract are equal to price minus profit. The relationship between program costs and profits is an inverse one, as program costs increase the profit decreases. Technically, a cost growth occurs when actual cost is greater than the initial estimate for a program. From

[1] "Defense Digest," Armed Forces Management, January, 1970, p. 17.

the government's standpoint a cost growth cannot occur on a FFP contract, as the government has agreed to pay a firm-fixed amount. Thus, the expression has meaning only in the context of cost contracts.[2] In actual practice, cost growths occur under various types of contracts, whether or not the contractor is reimbursed for additional costs.

Another misunderstanding that occurs relative to cost growths concerns the pertinent perspective.[3] Does a cost growth relate to one contract or a total weapon system? Individual contracts support the preacquisition phases of research, exploratory development, advanced development, and engineering development. A cost growth in one area may be balanced against a lower cost in another, so that the total is less than estimated. Thus, a cost growth may be acceptable, the touchstone being the total-system standpoint.

The very nature of scientific exploration tends toward cost prediction errors. The initial estimates which are based on projections into the unknown future are subject to considerable error.[4] This condition accrues as related to

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[2] W. E. Zisch, "Overruns Versus Increases in Systems Scope," Management Conference Seminar 5, Air Force Systems Command (Monterey, California: U.S. Naval Postgraduate School, 2-5 May 1962), p. 5-15-1.

[3] Harvard W. Powell, "Overruns--Cause, Effect, and Cure," Management Conference Seminar 5, Air Force Systems Command (Monterey, California: U.S. Naval Postgraduate School, 2-5 May 1962), p. 5-14-1.

[4] Burton H. Klein, "Policy Issues in Military Development Programs," in Defense, Science, and Public Policy,

performance, reliability, and cost of a system. Also the use of cost-type contracts contributes to the condition. The economic penalty for understating costs is nominal; therefore, contractors are motivated in this direction to obtain contracts.[5] Once the contract is in existence, then additional funds are requested.

Cost growths are not the exclusive domain of the DOD. An early example occurred during the Roman era. In the construction by Rome of an aqueduct for the town of Troas in Asia, the historian, Gibbon, observed that the final cost was more than double the original estimate.[6] In the commercial aircraft industry in 1944, the cost of an airplane scheduled for delivery in 1946 was estimated to be $550,000. When the aircraft was delivered in 1946, the cost had increased to $800,000.[7] A cost overrun was incurred in the construction of the Rayburn Annex to the House Office Building.[8] Not much of the developmental work in the private

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ed. by Edwin Mansfield (New York: W. W. Norton and Company, Inc., 1968), p. 105.

[5]A. W. Marshall and W. H. Meckling, Predictability of the Costs, Time, and Success of Development (Santa Monica, California: The RAND Corporation, October 14, 1959), p. 3.

[6]David Novick, Are Cost Overruns a Military-Industry-Complex Specialty? (Santa Monica, California: The RAND Corporation, March, 1970), p. 2.

[7]Charles L. Dearing and Wilfred Owen, National Transportation Policy (Washington, D.C.: The Brookings Institution, 1949), p. 204.

[8]Novick, op. cit., p. 3.

sector is placed on a cost-plus basis. This fact may account for the nominal commercial concern with cost growths.[9] Also commercial developments seldom venture out of the domain of proven technology. Most programs relate to minor modifications to existing products.[10]

Cost Growth Causation

The causes of cost growths are best considered in a dual framework. (See Figure 8, page 51.) Prenegotiation planning prior to time t_0 can structure the over-all contract period, so that a cost growth will occur. The second category of causes is linked to the actions taken during the production period. The causes can logically be divided into those of a preactivation and activation nature. Preactivation refers to the time period between technical and cost proposal preparation and the time that the contract is signed by both parties. Activation refers to contract administration and closure. In Table 5, the causes of cost growths are listed under these two generic headings.

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[9]Marshall and Meckling, op. cit., p. 3.

[10]Ibid., p. 2.

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A CONCEPTUAL COST MODEL FOR UNCERTAINTY PARAMETERS AFFECTING NE--ETC(U)

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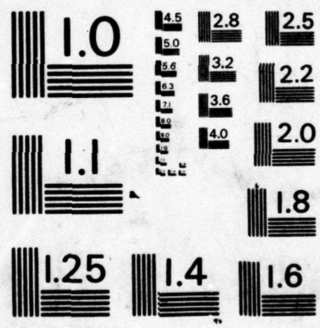

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 5

CAUSES OF CONTRACT COST GROWTHS

PREACTIVATION

1. <u>Cost Estimation</u>

   a. Cursory cost analysis

   b. Lack of competition

   c. Projection and estimating process

   d. Contractor underpricing

   e. Variabilities in past cost data

2. <u>Research and Development Specifications</u>

   a. Concurrency of research and development with production

   b. Extraneous design requirements

   c. Faulty technical planning

   d. Inadequate task definition

   e. Reliability problems

3. <u>External Environmental Factors</u>

   a. Budgetary constraints

   b. Corporate experience threshold

   c. Uncertainty estimation

4. <u>Internal Environmental Factors</u>

   a. Communication problems

   b. Contract type selection

   c. Risk analysis

   d. The negotiation process

ACTIVATION

1. <u>Economic Factors</u>

    a. Inflation

    b. Lack of economic penalty

    c. Order reductions

2. <u>Detailed Management Practices</u>

    a. Lack of cost control

    b. Inadequate control of subcontracts

    c. Changed reporting requirements

    d. Excessive reporting requirements

3. <u>General Management Practices</u>

    a. Changes in defense procurement policy

    b. Lack of contractor corporate organization

    c. Late delivery of government-furnished property

    d. Inadequate management controls

    e. Program stretch-outs

4. <u>Technological Considerations</u>

    a. Technological obsolescence

    b. Engineering changes

    c. Program reduction

The factors cited in Table 5 will be considered in sequence.

Cursory cost analysis.[11]--The volume of work often precludes an adequate evaluation of a cost proposal. Pricing personnel with limited experience contribute to this situation. When the price or cost analysis is performed by one activity for another, copies of negotiation summaries are often not sent to the pricing organization. Lack of feedback prevents a realistic appraisal of pricing practices.

Lack of competition.[12]--The sole-source nature for the majority of research and development procurements removes competition as a cost regulator. Secretary of Defense McNamara estimated that sole-source procurements cost at least twenty-five percent more than competitive ones.[13]

Projection and estimating process.[14]--Cost estimation may be based on actuals from past programs of a similar nature. A percentage of the actual as a base is added to the old figure. The new total is the estimate. A better procedure is to use single or multiple regression analysis to develop a profile of past cost data. The regression equation serves as an aid for the prediction of future costs. The

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[11]U.S., Department of the Air Force, Air Force Systems Command, A Summary of Lessons Learned from Air Force Management Surveys, AFSCP 375-2 (Washington, D.C.: Andrews Air Force Base, 1 June 1963), p. 61.

[12]William W. Kaufmann, The McNamara Strategy (New York: Harper and Row, Publishers, 1964), p. 198.

[13]The Southwestern Legal Foundation, op. cit., p. 207.

[14]Sutherland, op. cit., pp. 13-15.

assumption is that the future will have the variables interacting in the same relationship.

Contractor underpricing.--According to one estimate, fifty percent of all cost growths are the result of faulty original cost estimates.[15] The inaccurate estimates may be caused by defective engineering design, unexpected technical changes, incomplete cost data, and by purposely bidding low.[16] The latter process is referred to as a "buy in." Another form of "buy in," also referred to as "cost optimism," is where a contractor bids low in an effort to convince the contracting agency that a program's costs are low enough to be funded.[17] At a later date the firm reveals that the available funds will be inadequate.

Variabilities in past cost data.[18]--Past cost data may show variations in the prices paid for identical items. This dispersion may result from factors such as inflation, different lot sizes, and diverse cost bases for separate localities. Unless these variations are acknowledged, a cost growth may be built into the price negotiated for a system component.

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[15]"Defense Digest," Armed Forces Management, January, 1970, p. 17.

[16]Zisch, op. cit., pp. 5-15-1 to 5-15-2.

[17]Stekler, op. cit., p. 165.

[18]Sutherland, op. cit., p. 15.

Concurrency of research and development with production.[19]--The decision is made to produce a system or component before sufficient testing has been undertaken. The feasibility of production has not been ascertained. The unknown endogenous variables may cause difficult technical problems. These problems can increase program costs.

Extraneous design requirements.--The issue revolves around a functional design as opposed to an elaborate one.[20] A classic example of "gold-plating" involves a comparison of two turbine wheels from a nuclear weapon system. Part A was machined from stainless steel at a cost of $175. Part B was made of plastic at a cost of $2. Each part could do the necessary job. From the advanced development perspective, should a prototype incorporate modification to an existing system, or involve a more complex system which will perform somewhat better? In the latter case the uncertainties are more pronounced than in the former.

Faulty technical planning.--In evaluating the factors in the environment which relate to the requirement for more advanced weapons, a significant variable is overlooked. In other words, the wrong problem is solved. The research, exploratory development, advanced development, and engineering

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[19]Claude Witze, "Challenge to Industry," Air Force and Space Digest, January, 1970, p. 14.

[20]Kaufmann, op. cit., pp. 197-198.

development phases are programmed. Before the weapon can be produced in quantity the specific application is obsolete. Plans must be revamped, and funds reprogrammed.

Inadequate task definition.--This facet refers to the detailed aspects of the planning for a specific contract.[21] The work statement is written in vague and general terms. The contractor interprets the language and pursues a certain path of inquiry. A later analysis may disclose a divergence. The need is for definitive work statements and specifications, whenever possible. Confusion may exist in terms of unrealistic delivery schedules. The schedules can be met only by an increase in contract costs. Thus, a tradeoff is effected between time and cost.

Reliability problems.[22]--Reliable performance is the goal of most production hardware. At some point a model is fabricated. Operational conditions are simulated. Latent problems may appear in testing and are difficult to predict in advance. The process of reliability validation is an empirical one. Experimental equipment components are developed and operationally tested until a breakdown occurs. The defective part is examined and corrections made. The process continues until the results are acceptable. If acceptable

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[21] Zisch, op. cit., p. 5-15-1.

[22] Klein, op. cit., pp. 9-10.

performance is not attained, design modifications may have to be accomplished.

Budgetary constraints.--The planning-programming-budgeting process allocates funds to the various research and development organizations. Each one usually receives less than requested. Wanting to obtain as much coverage as possible, the activity may fund a program in a limited manner.[23] The contractor performs in anticipation of an expanded funding level. The extra funds possibly will not materialize. Thus a cost growth is incurred.

Corporate experience threshold.--A company with little or no experience in the defense industry has a tendency to underestimate the uncertainty in government contracting.[24] This fact is reflected in cost estimates and delivery schedules which are overly optimistic. With no room for slippage, even minor problems can contribute to a cost overage.

Uncertainty estimation.--Exogenous uncertainties may be difficult to anticipate. Similar problems accrue to endogenous ones. During procurement planning, each participant needs to perform a risk analysis. The objective is to

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[23]Procurement and Finance Council, Risk Elements in Government Contracting (Washington, D.C.: Aerospace Industries Association of America, Inc., October, 1970), pp. 22-25.

[24]Zisch, op. cit., p. 5-15-3.

identify external and internal uncertainties. Sometimes firms introduce new products based on experience with a similar established one. The similarities and differences are studied. The knowledge is used in introducing the new product. An analagous process might be used in development.

Communication problems.--The lack of adequate feedback has hindered decision making on development programs.[25] Some program managers have not delegated sufficient authority to subordinates. This combination is mutually perpetuating and time consuming. Delays in obtaining information plus the time required to make a decision contribute to cost increases.

Selection of contract type.--Scherer cites a study of 171 CPFF contracts that showed an average cost growth of 18 percent.[26] Another study revealed that two out of three CPFF contracts ended in a cost growth. CPFF and CR contracts usually contain a best-efforts clause which permits experimentation as related to program direction and methodology. Also the fixed fee may be a weak incentive for cost control.

The negotiation process.--A practice in the defense industry has been the inflation of cost estimates. Two detrimental effects ensue: (1) No standard amount is added.

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[25]*Ibid*., p. 5-15-3.

[26]Scherer, *op. cit*., pp. 154-155.

Negotiations sometimes reduce proposed program costs too much. In the bilateral monopoly relationship the contractor may be forced to accept unrealistic cost estimates. The impact is to distort the final negotiated cost. (2) Not all firms add the cushion to their estimates. Consequently, an inexperienced company could agree to an underestimated contract price. The basic concept behind this inflation of costs is that large initial demands improve the probability of negotiation success.[27]

Inflation.--Increased costs for system components translate into higher costs for systems. Defense planners cite inflation as the paramount reason for the increasing costs of weapon systems.[28] For example, in World War II, an average fighter plane cost $50,000., as compared with $11.5 million in 1971. (See Table 6 for other comparisons.) For a research and development contract negotiated with no provision for inflation, actual costs may show a significant increase. On one Congressional list of 35 major-weapon systems with cost growths which totalled $19.9 billion, inflation accounted for $3.1 billion or 15.4 percent of the total.[29]

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[27]Chester L. Karrass, The Negotiating Game (New York: The World Publishing Company, 1970), p. 18.

[28]"The Real Problem--How to Cut Defense Billions," U.S. News & World Report, June 21, 1971, p. 32.

[29]"Defense Digest," Armed Forces Management, January, 1970, p. 17.

TABLE 6

COMPARATIVE COSTS OF WEAPONS SYSTEMS
(Millions of Dollars)

Item	World War II	1971
Aircraft Carrier	55.00	750.0
Bomber	0.50	25.0
Destroyer	6.50	90.0
Submarine	5.00	170.0
Tank	0.07	0.6

Source: "The Real Problem-How to Cut Defense Billions," U.S. News & World Report (June 21, 1971), p. 32.

Lack of an economic penalty.--Stekler indicates that under cost-type contracts, contractors expend, not their own, but public funds.[30] A fixed fee will be paid plus costs. Should the contractor for research and development control costs when the firm has idle capacity or should this capacity be used on the contract? If the facilities and personnel are used, then at least some of the charges will be reimbursed. Thus, an inducement to incur a cost growth. Further, a cost growth on one or several contracts does not seem to deter future awards to the delinquent contractor.

Order reductions.--Contractor prices for units often relate to the quantity produced for one single contract and

[30]Stekler, op. cit., pp. 165-166.

not for the complete inhouse contract load.[31] Consequently, when the procuring agency cancels a portion of an order, the unit costs for the remaining items may increase. In research and development contract funding, limitations may cause the curtailment of a program. If special tooling has been ordered which can only be used on a particular contract, a cost overage may develop.

Lack of cost control.--Some manufacturing firms do not know their transportation costs, yet believe they have these costs under control.[32] This same condition prevails for some research and development programs. Costs are not kept individually for each contract. Costs are allocated to programs rather than being charged, based on recorded actuals. Essentially, no uniform cost accounting standards exist for the defense industry.[33] Each firm prepares and maintains its own system.

Inadequate control of subcontracts.--Excess costs incurred on subcontracts are passed on to the prime contractor and eventually the government. The prime contractor has the responsibility of monitoring subcontractor

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[31]"Taking the Defensive on High Arms Costs," Business Week, December 6, 1969, p. 70.

[32]Constantin, op. cit., pp. 44-45.

[33]Kenneth M. Jackson, "The Feasibility Study of Uniform Cost Accounting Standards," NCMA News Letter Anthology, Vol. No. 1, 1968-1969-1970 (Inglewood, California: National Contract Management Association, June, 1970), pp. 61-63.

performance. Some of the same problems are germane for subcontract cost growths, such as inadequate cost control, cursory price analysis, inexperienced subcontractors, and cost optimism.[34]

Changed reporting requirements.--Frequent changes in reporting requirements may be disruptive. In some instances, contractors delay in making the changes. Significant information concerning cost, technical problems, and delivery schedule deviations, is not received on a timely basis. Thus, decisions are not made.

Excessive reporting requirements.--Unless reporting requirements for a specific contract are coordinated, the contractor may be faced with duplicate demands. Management may not be aware of the existence or extent of the duplication nor its cost.[35] Too much information can hinder the decision process. This condition results from the inability of management to identify significant details or trends from the mass of available data.

Lack of timely information.--Reporting requirements may be optimal relative to changes and their magnitude. However, lacking timeliness, information may be of questionable value. Many management information systems provide a

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[34] A Summary of Lessons Learned from Air Force Management Surveys, op. cit., p. 65.

[35] Ibid., p. 29.

complete report every thirty days. By the time these data are evaluated, five or six weeks will have elapsed. Variations from cost have occurred which can be hard to control.

Changes in defense procurement policy.--Reporting requirement changes have been mentioned. The key is the reaction of subordinate activities to guidance from higher levels of command. For example, the use of CPFF contracts is classic. In 1959, approximately 40 percent of all procurement dollars were obligated under cost-reimbursement contracts. By 1969, this percentage had fallen to 22 percent.[36] This trend created concern in the defense industry. This reaction seemed to refute two principles gleaned from twenty-four years of contracting: (1) different programs require the selection of different contract types, and (2) higher program risks require the application of a flexible step-by-step contracting approach.[37]

Lack of contractor corporate structure.--Some firms do not have an organizational structure which will permit timely decisions.[38] No one has the authority to make decisions without the activation of higher approval echelons.

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[36]Logistics Management Institute, Briefings on Defense Procurement Policy and Weapon Systems Acquisition (Washington, D.C.: Logistics Management Institute, December, 1969), pp. 16-28.

[37]Edgar E. Ulsamer, "Mastering Technology," Air Force and Space Digest, September, 1970, p. 81.

[38]A Summary of Lessons Learned from Air Force Management Surveys, op. cit., p. 75.

The situation contributes to cost and delivery deviations. When problems occur, no one has the authority to take corrective action.

Late delivery of government-furnished property.--Some research and development contracts are predicated on the use of government special-test equipment. The provision allows the placement of the contract at a lower initial cost. Should the equipment not be available on schedule, this situation creates costly and time-consuming delays.

Inadequate management controls.--Management control depends on access by managerial personnel to adequate and timely feedback information. Insufficient data are as detrimental as excessive information. The manager must seek the balance between the cost of acquiring and maintaining informational efficacy, which is optimal.

Program stretch-outs.--Scherer cites five instances for which shortages of funds led to schedule slippages.[39] When no additional funds were available, a decision was made to stretch-out the program, to permit funds to be added at a later time. Thus, a tradeoff was effected between time and cost. The passage of time often attenuated the initial shortage of funds.

Technological obsolescence.--This variable relates to exogenous uncertainty. Technological factors lead to

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[39] Scherer, op. cit., pp. 59-60.

changes in a weapon's sophistication level. Such factors can make a developmental effort obsolete.[40] Cancellation of the program will be more expensive, since sunk costs are lost. Program redirection will salvage some past costs. However, total costs will probably increase.

Engineering changes.--These changes relate to endogenous uncertainties. Problems develop as a program is being conducted. Testing can reveal defects, necessitating corrections. A change in design may result from an initial design error.[41] In any event, a change order is processed which may or may not increase the contract cost.

Program redirection.--Once a development program is in progress, difficulties occur in trying to shift emphasis or to abandon the basic concept underlying the endeavor.[42] Changes generally are evolutionary or explosive in nature. For research and development programs this latter type is costly. Progress needs to be gradual and cumulative. Drastic changes in basic concepts may require redirection or abandonment.

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[40] U.S., Department of the Air Force, Air Force Systems Command, Management Conference Seminar 1 (Monterey, California: U.S. Naval Postgraduate School, 2-5 May 1962), p. 1-11-4.

[41] Mendel Rivers, "Who is to Blame for Cost Overruns?" Government Executive, June, 1970, p. 192.

[42] Scherer, op. cit., pp. 25-26.

CHAPTER VIII

EFFORTS TO CONTROL COST GROWTHS

Historically, the FFP contract has been deemed most desirable to procure supplies and services for the government. Related to this preference was the emphasis placed on formal advertising.[1] The basis for this public preference is competition and the moral obligation of the contractor to deliver the goods and services even when costs exceed the price ceiling. Advertised procurements supported by firm-fixed price contracts were the rule except during the period of a national emergency or exigency.

The post-World-War-II era brought an unprecedented expansion of research and development. The advertised procurement and fixed-price-contract combination did not serve well as supporting mechanisms for scientific programs. Educational and nonprofit institutions, as well as some commercial firms, were ill equipped to absorb losses from cost growths under FFP contracts. The increased emphasis on research and development, the increasing complexity of weapon

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[1] Logistics Management Institute, op. cit., p. 8.

systems, and the tendency for weapon specialization had a catalytic impact on the magnitude of the problem. A representative sampling of the attempts to cope with this problem will be examined briefly. Also the effectiveness of the measures will be assessed. The measures to control cost growths will be considered under three headings: preactivation, activation, and environmental patterns.

Preactivation

The decision to include a measure under a particular heading is somewhat arbitrary. The classes are interlinked and overlap. Each one was developed to stimulate activity for the minimization of cost growths. The primary device to control costs has been contract type. Prior to 1950, the FFP contract was the dominant one used. Emphasis then shifted to the use of cost-reimbursement contracts. On a procurement-dollar basis, 13 percent of the contracts were cost reimbursement in fiscal year 1951. This percentage had increased to 43 by fiscal year 1960. Reaction against cost growths under cost-reimbursement contracts caused the proportion to decline to 21 percent by fiscal year 1966. A policy was initiated in 1961 to encourage the use of incentive contracts. On the basis of contract awards, incentive contracts were 18.5 percent of the total in 1959, but had increased to 27.8 percent by fiscal year 1965.[2] The

[2]Fisher, op. cit., p. 3.

fixed-price-incentive contract became the vehicle for procuring highly advanced systems.[3]

The "Should Cost" concept was adopted by the U.S. Navy. The goal is the evaluation of a contractor's total production operation.[4] "Should Cost" is particularly suited to sole-source contractors. The condition for application of "Should Cost" is when a contractor has ceased to be an efficient producer. The program contemplates a thorough investigation of a contractor's operation to identify inefficiencies and then appropriate corrective action. The process reveals what costs ought to be, if the firm was an efficient producer. In one study the U.S. Army reduced a sole-source procurement with Raytheon by seventeen million dollars.[5] The technique is relatively new and has not been used extensively.

In terms of design policy, the functional approach is now being emphasized. Weapon systems will be designed for minimum necessary performance.[6] This change is directed toward "gold-plated" contracts.

Contractual provisions have been used for control purposes. Cost-reimbursement contracts have been

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[3]Drake, op. cit., p. 121.

[4]"'Should-Cost' Is the New Weapons Test," Business Week, May 30, 1970, p. 48.

[5]Ibid.

[6]"A Retreat from Gold-Plated Contracts," Business Week, July 11, 1970, p. 96.

incorporating a "Limitation of Cost" clause. The clause requires the contractor to notify the contracting officer when actual cost expenditures and commitments reach eighty-five percent of the estimated cost under the contract.[7] The contractor incurs costs beyond the original estimate at his own risk and expense.

An effort to stimulate competition in defense contracting was initiated by Secretary of Defense, Robert McNamara. Increased competition was wanted to reduce costs and to keep them at a low level. In fiscal year 1961, 32.9 percent of procurement dollars were placed competitively.[8] In fiscal year 1969, the figure was 40 percent.[9]

Multi-year procurements were conceived with the goal of stimulating competition. A contract for one year often required contractors to purchase special-test equipment. A one-year amortization base precluded many contractors from taking part in the weapons acquisition process. This factor contributed to the preponderance of sole-source procurements. The multi-year procurement mechanism incorporated requirements into a program which spanned several years. Contractors could amortize initial costs over a longer period of

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[7]The Southwestern Legal Foundation, Government Contracts and Procurement (New York: Commerce Clearing House, Inc., 1963), p. 80.

[8]Ibid., pp. 206-207.

[9]Logistics Management Institute, op. cit., pp. 26-27.

time. One-year contracts encountered uncertainty as related to extension of the program. Budgetary uncertainty was reduced by the multi-year procedure. The uncertainties which adhere to the cost estimation process, however, are increased with a longer projection period.[10] Also the possibility of program cancellation is enhanced.

Another effort to reduce sole-source procurements was the establishment of formal source-selection procedures.[11] A point system was structured to remove subjectivity from the source-selection process. The effort was directed mainly at major full-scale development and large production endeavors. However, when more than one source is available, the methodology can be used in all four of the weapons acquisition phases.

Component breakout relates to efforts to increase commercial participation in weapons development and production. Instead of contracting for a major system or subsystem as an entity, the program is partitioned. Competition is stimulated and the defense-industry base is broadened. Firms are stimulated to specialize and practice market segmentation. However, this process increases production dependency and its innate uncertainties.

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[10] Procurement and Finance Council, Risk Elements in Government Contracting (Washington, D.C.: Aerospace Industries Association of America, Inc., October, 1970), p. 8.

[11] Logistics Management Institute, op. cit., p. 21.

Two-step formal advertising was an attempt to inject negotiation characteristics into the advertising method. Its purpose was to promote the competitive element in contract awards.[12] In effect, the procedures combine the steps of both negotiation and formal advertising. The first sequential step involves technical competition in response to a request-for-proposal. The second step promotes price competition through the invitation-to-bid process. A study conducted by the Air Force Eastern Test Range revealed that 2.7 bidders participated in the award of 31 contracts.[13] Thus, competition was enhanced. Unfortunately, effectiveness of cost control under the arrangement was not investigated.

Activation

In the activation category the administration of the contract is effected. Emphasis is placed on techniques to facilitate the management process. Production at the lowest possible cost commensurate with reliable quality must be the stated goal of the defense industry. In attaining these objectives the emphasis is on the activities of both governmental and industrial managers to exercise effective surveillance and control.

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[12] James Strieringer, "An Introduction to Two-Step Formal Advertising," NCMA News Letter Anthology, Vol. No. 1, 1968-1969-1970 (Inglewood, California: National Contract Management Association, June, 1970), p. 47.

[13] *Ibid*., p. 48.

In the past, a program manager has been assigned to major weapon systems. This position has included the responsibility to manage all aspects of the system being developed, but not the authority to accomplish the contemplated goals.[14] A program manager needs experience, good judgment, stamina, and leadership capabilities.[15] Lack of authority to demonstrate these qualities has led to an absence of effective program control. An awareness of the situation has stimulated the top defense planners to delegate more authority to program managers. For example, on the B-1 bomber program, a recent decision was made to reduce program costs by eliminating some experimental testing. The decision was made by the program manager without a series of subsequent reviews being required.[16]

Design changes have contributed to cost growths on development programs. Many changes to a system or subsystem are made without considering the impact on cost.[17] Efforts to curb this activity require technical changes to be priced and written into the contract. Also a fixed-cost ceiling is placed on the program. This limit may require a technical

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[14]"Project Bosses Get More Power," Business Week, March 20, 1971, p. 96.

[15]Lawrence A. Skantze, "The Art of the Program Manager," Air Force and Space Digest, November, 1969, p. 81.

[16]"Project Bosses Get More Power," Business Week, March 20, 1971, p. 101.

[17]"A Retreat from Gold-Plated Contracts," Business Week, July 11, 1970, p. 97.

change to be effected by means of a tradeoff. For example, fewer units can be purchased or increased costs can take place only if costs are curtailed in another area.

An approach with a definite goal of cost reduction through design changes was the Value Engineering Program. The goal is to motivate the contractor to propose cost-reducing design changes. The efficacy of the program has been diminished by sporadic and resistant administration. The people who evaluate the proposed changes are the original designers. To change seems to be an admission that the designer was wrong in the first instance. The full potential of the program has not been realized.[18] In response to the cost-growth problem, management information systems have proliferated.[19] The objective was to obtain improved cost visibility and control. However, the requirements imposed on contractors are costly and complex. For example, the Cost/Schedule Control Systems Criteria (C/SCSC) has created greater risks and costs. These burdens include excessive paper documentation in response to a request-for-proposal, varying interpretations of system requirements, and voluminous data demands. Instead of improved communication, the system has created confusion. Additionally, an effective coordination system does not exist. Contractors face an array of

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[18] Risk Elements in Government Contracting, op. cit., p. 8.

[19] Ibid., pp. 44-46.

information system demands imposed by numerous governmental agencies.[20]

Governmental action was taken to improve the financial status of contractors during the production period. The goal was to augment working capital. Financial assistance took the form of larger progress payments, expedited payments, and government loan assistance.[21]

Finally, efforts have been expended to rate contractor performance. A rating system has been used for research and development contractors.[22] In general, these attempts have placed emphasis on technical performance. Little or no concern has been directed to the cost-growth problem. The occurrence of a cost-growth did not appear to be a determinant as related to subsequent awards.

Environmental Patterns

Both preactivation and activation variables dealt with the cost-growth problem on a functional or procedural basis. The endeavors in this section relate mainly to contractual philosophy.

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[20]G. N. Virgil, "Is There a Proper Way to Control Government Reports?" NCMA News Letter Anthology, Vol. No. 1, 1968-1969-1970 (Inglewood, California: National Contract Management Association, June, 1970), p. 78.

[21]Logistics Management Institute, op. cit., p. 23.

[22]U.S., Department of the Air Force, Air Force Systems Command, Air Force Laboratory Procurement Management, AFSCP 70-3 (Washington, D.C.: Andrews Air Force Base, 30 June 1967), pp. 5-18 to 5-19.

The early 1960's brought centralization of decision making to the weapons acquisition process.[23] The military services were separately organized but administered by the Secretary of Defense. The objective was to eliminate duplicate weapon systems.[24] The phrase, "commonality," meant that one system would be developed for all military departments.

By 1969, decentralization was being effected.[25] Most of the management decisions were to be made by the top management officials of the military services. This pattern established the atmosphere for the F-15 fighter program. The impact of decentralization has been discussed in terms of the program manager's role.

The program definition phase was an attempt to enhance design definition.[26] The study procedure was to be regulated by competition. Two or more contractors would bid for the contracts. At least two contracts would be placed. The goal was to remove as much uncertainty as possible from the developmental endeavor. The emphasis would be on planning. Subsequently, a contract would be placed for the actual development of the weapon system. This phase has been

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[23] Logistics Management Institute, op. cit., pp. 59-60.

[24] Anderson, op. cit., p. 166.

[25] "The Dogfight Over the F-15," Business Week, December 20, 1969, p. 97.

[26] Art, op. cit., pp. 94-96.

characterized by excessive documentation. The paperwork required to define the program often ranged between 20,000 to 50,000 pages.[27]

An effort to obtain the benefits of price competition was the total package procurement (TPP). The concept envisioned the negotiation of a contract for the engineering development, production, and support phases of the weapons acquisition spectrum.[28] The concept was applied to the F-111 fighter and the C-5A transport aircraft programs.[29] Both of these programs experienced significant cost growths. Most of the total package procurements were placed on a firm-fixed-price basis. The arrangement placed the burden for bearing the significant portion of the unanticipated exogenous and endogenous uncertainty on the contractor.[30]

An Analysis of Effectiveness

One measure of cost performance effectiveness for contractors is to compare the actual program costs with those estimated for the program initially.[31] This procedure will reveal how effective past efforts have been in alleviating the cost-growth problem. If the occurrence of a cost

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[27] Anderson, op. cit., p. 166.

[28] Logistics Management Institute, op. cit., p. 24.

[29] Anderson, op. cit., p. 166.

[30] Risk Elements in Government Contracting, op. cit., p. 8.

[31] Stekler, op. cit., p. 164.

growth is assumed to constitute evidence that cost control is lacking, then cost control can be established as the touchstone. The minimal occurrence of cost growths would imply effective controls, while a pattern of cost-growth prevalence would imply the opposite. Three sample time periods will be sufficient to ascertain the existence of any pattern.

Peck and Scherer report that in a sample of 12 programs, developmental program cost estimates on the average resulted in actuals exceeding estimated costs by 220 percent.[32] Variances on initial contracts were much larger than on later ones. The sample programs included the B-58 strategic bomber, F-105 tactical fighter-bomber, Polaris Intermediate Range Ballistic Missile (IRBM), the Nike Ajax surface-to-air guided missile. The study was published in 1962 and covered approximately the decade of the 1950's. In the sample the cost-growth variance ranged from two to seven times original cost estimates.[33]

In 1969, a Congressional list of 35 major weapons system procurements revealed that 27 of the programs showed cost growths in the amount of 19.9 billion dollars.[34] Individual cost growths ranged from 8 million dollars for the Walleye II TV-guided glide bomb to 4,011 million dollars for

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[32]Peck and Scherer, op. cit., p. 412.

[33]Peck and Scherer, op. cit., p. 429.

[34]Witze, op. cit., p. 14.

the F-111 fighter. The greatest percentage increase was 395 percent for the Navy's Mark 48 torpedo.

A news release in March, 1971, quoted a General Accounting Office report which cited cost growths totaling 33.4 billion dollars.[35] The Mark 48 torpedo program reflected a cost growth of 3 billion dollars for the largest increase. The Minuteman III at 2.9 billion was next. Data limitations do not permit the identification of the programs which were on both the 1970 and 1971 lists. However, the programs must have been approximately the same ones. The increase in one year was from 19.9 to 33.4 billion dollars. Over the twenty-year period measures to reduce cost growths have apparently not been too effective.

Summary

The situation can be succinctly described as the application of measures to treat the symptoms of the disease on an individual basis. Yet, no measure has been fruitful in terms of coping with cost growths by identifying and working with the basic cause of the disease.

The Aerospace Industries Association in a series of reports has directed its attention to the uncertainty parameter. Their reports examine this difficult variable and its treatment by the government. The Logistics Management Institute reports numerous studies which may impact on the

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[35] "Weapons Cost Overruns Revealed," The Daily Oklahoman, March 19, 1971, p. 3.

DOD-Contractor relationship.[36] The studies may be summarized as follows:

(1) Efforts to validate and expand the data base for cost estimates,

(2) Improved mathematical and statistical estimating techniques, and

(3) Endeavors to increase the visibility of contractor operations.

In October, 1970, the Deputy Secretary of Defense issued a memorandum to the military departments. This document emphasized the role of judgment in the weapons acquisition process.[37] The information disseminated to Air Force Commands emphasized the approach to be taken toward the treatment of technical risk by the government.[38]

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[36]Logistics Management Institute, DOD-Contractor Relationship--Preliminary Review (Washington, D.C.: Logistics Management Institute, March 19, 1970), p. 10.

[37]David Packard, Memorandum for Subordinate Echelons: Reduction of Procurement Directives (Washington, D.C.: The Deputy Secretary of Defense, October 3, 1970), pp. 1-2.

[38]David Packard, Memorandum for Subordinate Echelons: Policy Guidance on Major Weapon System Acquisition (Washington, D.C.: The Deputy Secretary of Defense, May 28, 1970), pp. 1-6.

CHAPTER IX

A CONCEPTUAL COST MODEL

Four parameters and their interactions emerge as the key conceptual issues. The parameters are time, uncertainty, information, and cost. An inverse relationship exists between information and uncertainty. The significant characteristic of the information variable is content and not necessarily its magnitude. The more information a given data element can supply, the more efficacious a certain management information system. As the informational efficacy decreases, the uncertainty in a specific situation increases. Increased information reduces uncertainty. For a definite time frame additional information can be obtained at an incremental cost. Also as time passes, information in the environment of the decision maker increases. Its amount and content can be magnified by the expenditure of funds. Program costs will increase directly with increases in uncertainty. The more uncertain the future, the less information available for decision-making purposes. The more uncertain the future events, the more costs can be expected to vary relative to

initial estimates. If the immediate environment of the decision maker is represented by a closed system, then it can be treated as a component in a communication channel.

Communication Factors

In The Mathematical Theory of Communication, Shannon posits a model of a general communication system.[1] (See Figure 15.) The input source prepares a message for

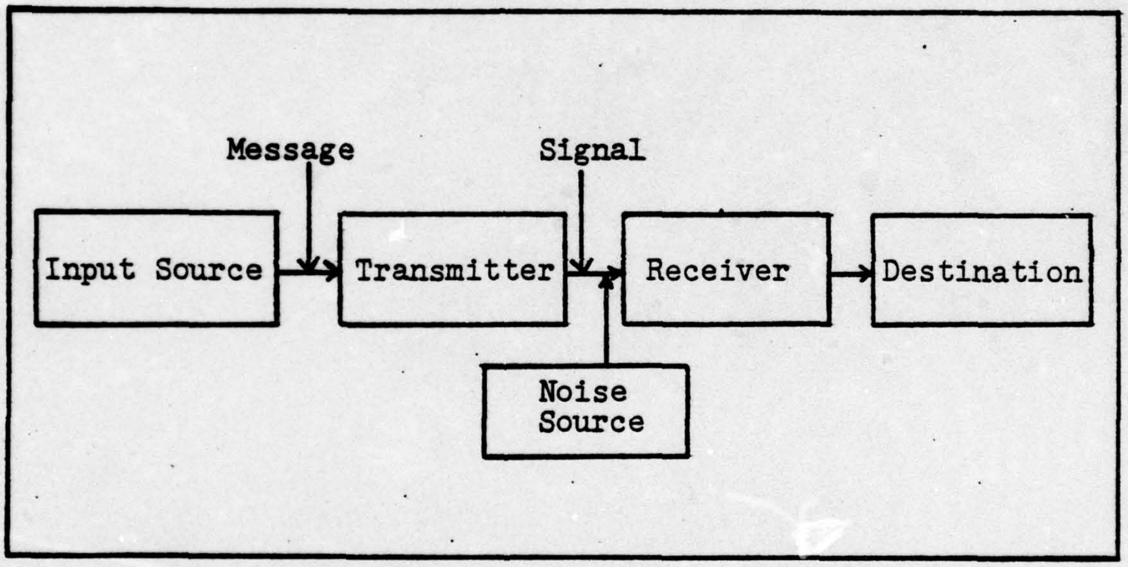

Fig. 15.--General communication system

Source: Claude E. Shannon and Warren Weaver, The Mathematical Theory of Communication (Urbana, Illinois: The University of Illinois Press, 1949), p. 5.

transmission. The message is encoded and transmitted, as an electrical signal. During transmission the message can be

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[1] Claude E. Shannon and Warren Weaver, The Mathematical Theory of Communication (Urbana, Illinois: The University of Illinois Press, 1949), p. 5.

distorted by noise. The noise consists of static or any other unwanted addition which tends to modify the signal. The receiver translates the signal into a message for evaluation by the destination. Although this model was developed by Shannon primarily for telegraph and telephone systems theory, it can be adapted to represent a management information system. An examination of Figure 16 reveals the necessary changes. The perspective is different. The decision maker is the receiver, and the emphasis is on the message which is being received, rather than on transmission.

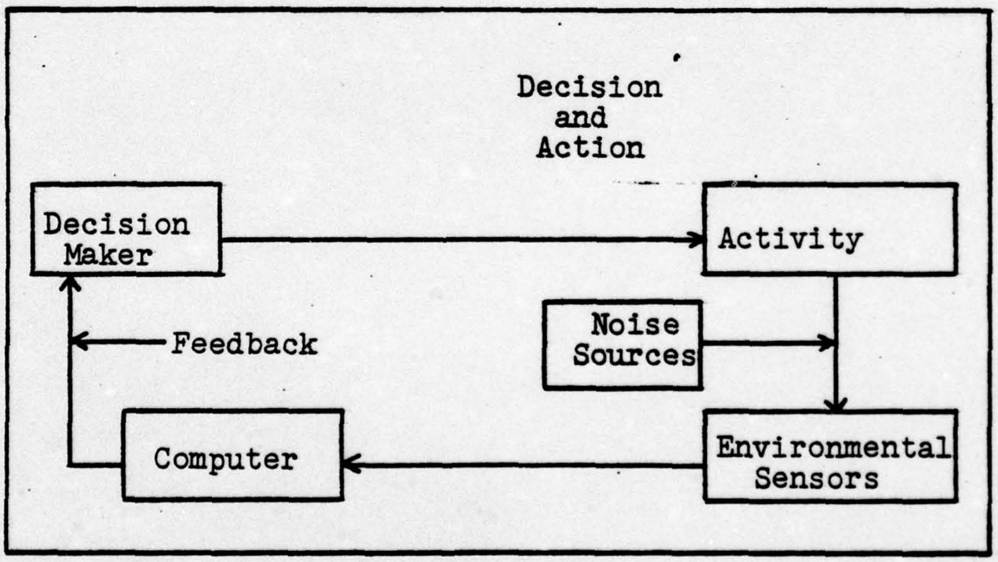

Fig. 16.--Contract administration system

The decision maker represents the initial stages of the contract-life cycle, ranging from submission of the contractor's proposal to contract finalization. The activity node consists of contract administration and closure.

Environmental sensors obtain feedback relative to the status of contract cost and other germane variables. The data returning to the computer can be distorted or inadequate. Its informational value is affected by the noise in the system. The decision maker and his immediate environment are a closed system and a subsystem of the over-all system. Four important characteristics of the process require elaboration.

Information.--As stated, information is difficult to define. In communications theory, the problem is compounded. This fact results from Shannon's definition of information. In communication theory, information relates to the number of choices available to the decision maker, or to the number of possible events which could occur.[2] More specifically, the amount of information is measured by the logarithm of the number of available choices. However, as Weaver asserts, information in communication theory does not encompass meaning.[3] The conclusion results from Shannon's emphasis on the technical aspects of sending the message in signal form. In this study, informational content is critical. The validity of decisions made will stem directly from the efficacy of the data content. Therefore, a distinction must be made between information and its content or meaning. The term, informational efficacy, will be adopted to refer to content or

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[2]Shannon and Weaver, op. cit., pp. 100-101.

[3]Ibid., p. 99.

meaning, whereas, information will be a measure of the amount of data. In essence, Shannon's definition will be observed.

Entropy.--The expression has been defined as a measure of disorder in a closed system. This definition needs to be refined. Entropy is a measure of the amount of information in a system; in particular, it encompasses the number of choices available to the decision maker.[4] Entropy relates to the degree of randomness of the information, not to informational efficacy. As entropy increases, information increases, uncertainty increases, freedom of choice increases, but the informational efficacy decreases as related to a specific data source. In accordance with the second law of thermodynamics, the tendency is for the entropy in a system to always increase.[5] Order in the system equates to informational efficacy. Disorder is measured by entropy. Increased entropy degrades informational efficacy. Let H represent entropy and IE represent informational efficacy, then:

$$H + IE = 1 \quad \text{and}$$
$$IE = 1 - H.$$

From the definition of information and its relationship to entropy:[6]

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[4] Ibid., p. 103.

[5] Shannon and Weaver, op. cit., p. 103.

[6] Shannon and Weaver, op. cit., p. 105.

$$H = -[p_1 \log p_1 + p_2 \log p_2 + \dots + p_n \log p_n]$$
$$= -\int_{-\infty}^{\infty} p(x) \log p(x)\, dx$$
$$= -\sum_{i=0}^{n} p_i \log p_i$$

where $p_1, p_2, \dots, p_n$ stand for the individual probabilities of choice. In a closed system the tendency is for entropy to increase. A source of negative entropy is necessary to counter this tendency.[7] In other words, the informational efficacy of the data in the system needs to be augmented. As negentropy increases, the entropy in the system decreases. Thus, the feedback system has as its purpose to provide a source of negentropy.

The measurement of entropy.--Probability refers to the possibility that a specific or unique data element will appear. The occurrence of a given data element is considered an event, for example, a certain cost. The relationship between total uncertainty and entropy is a direct one. The reference is to both anticipated exogenous and endogenous uncertainty and to unanticipated exogenous and endogenous uncertainty. As the entropy or number of choices increases, the total uncertainty in the situation increases. As mentioned, the amount of uncertainty for any individual event

[7]Wilson and Wilson, op. cit., p. 257.

can be measured by its probability of occurrence. This factor permits the entropy for a probability distribution to be measured. The probability distribution is derived subjectively, based on intuition and judgment. Consider the situation of Table 7. The entropy for the probability distribution can be calculated.[8] (See Table 8.) The entropy for the distribution is equal to .4582. The probability distribution in Table 8 is platykurtic. The entropy will be highest when events are most nearly equally probable. When an event becomes much more probable than the others in the distribution, the entropy decreases. (See Table 9.) Thus, with the second probability distribution the entropy decreases from the .4582 value of Table 8 to a value of .1087. Possible entropy values will range from zero where no entropy is present and probability of occurrence is unity to a value of one for entropy and the probability is equal to zero. Thus, information is measured by entropy which is a measure of disorder. Informational efficacy is order and is measured by negentropy.

Economic cost.--In a perfectly competitive market, a necessary condition is that each buyer and seller must have complete information or certainty about prices and the availability of alternative goods.[9] In recognition of the

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[8]Schmitt, op. cit., p. 168.

[9]Hibdon, op. cit., p. 173.

TABLE 7

PROBABILITY DISTRIBUTION

Cost Estimate	Probability	Expected Value
$400	.4	$160
600	.4	240
850	.2	170
	1.0	$570

TABLE 8

ENTROPY COMPUTATION NUMBER 1

Probability	-p log p[10]
.40	.1592
.40	.1592
.20	.1398
1.00	H = .4582

TABLE 9

ENTROPY COMPUTATION NUMBER 2

Probability	-p log p
.95	.0212
.04	.0595
.01	.0200
1.00	H = .1087

[10]Schmitt, op. cit., p. 369.

semantic problem in communication theory, information about the market is synonomous with informational efficacy. Thus, with complete informational efficacy, no cost estimate will ever deviate from the original value. In this context, economic cost includes profit as a payment for a factor of production. This payment is to the owners who are residual claimants of the revenue of a company.[11]

Model Formulation

The foundations have been established for a macroscopic model which depicts contract cost theory. The assumptions of the model can be summarized as follows:

(1) The theory is normative rather than descriptive.

(2) The effective cost for a program can be represented by the ratio of target costs to the informational efficacy of the data in a closed decision-making system.

(3) Perfectly competitive markets exist. Contracts are let on a competitively negotiated basis. This assumption will be relaxed subsequently.

(4) Entropy is a measure of the information or disorder in a system; whereas, negentropy is a measure of the order in a system and can be equated with informational efficacy.

(5) The informational efficacy varies inversely with the number of choices or possible events which can occur

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[11] Hibdon, op. cit., p. 355.

as related to the decision-making system. If one course of action seems almost certain, then the informational efficacy is increased and vice versa.

(6) Since contract price usually includes an amount for profit, this fact must be considered. Economic cost includes the profit factor and can, therefore, represent contract price.

(7) No limitations on funding exist. Programs can be fully funded in anticipation of a possible cost growth.

The model stresses the relationship between contract cost and the informational efficacy of the system. Let this relationship be expressed by the expression:

$$C_E = \frac{C_I}{IE}$$

where C_E stands for the expected economic cost of the program, C_I for the initial expected economic cost, and IE represents informational efficacy.

Informational efficacy is equal to unity minus entropy, thus the formula may be restated.

$$C_E = \frac{C_I}{1-H}$$

Under the assumption of perfect competition where certainty prevails, H is equal to zero and thus, C_I divided by unity gives C_I and C_E is equal to C_I. This outcome for the conceptual model verifies the assertion that under conditions of certainty no cost estimate will be in error.

However, in Chapter IV the relationship between the government and the contractor was described as that of bilateral monopoly. In Chapter II the statement was made that in fiscal year 1969, 73 percent of the total procurement actions were placed on a sole-source basis. This occurrence seemed to validate the monopoly relationship. The impact on the model is the introduction of uncertainty which derives from the condition of imperfect informational efficacy. The change of assumption from a perfect to an imperfect-market structure allows IE to be not just one, but a range of values for each specific cost estimate. In Table 10 IE is assigned a range of values for an expected cost of $570. This figure is taken from Table 7. These values are plotted in Figure 17. The curve R illustrates the postulated relationships. As the informational efficacy increases, program costs decrease. The curve shows that the relevant range of IE values for decision-making purposes is from approximately zero to approximately unity. The curve R is asymptotic to both the ordinate and abscissa axes. However, outside of the relevant range from zero to unity, changes in informational efficacy have very little impact on cost.

Increases in entropy reduce the IE value. These changes in entropy technically result for a program from noise. In the systems context, noise results from factors such as cursory cost analysis, contractor underpricing, extraneous design requirements, technical changes, and

TABLE 10

EXPECTED COST FOR IMPERFECT MARKETS

IE	C_E	IE	C_E	IE	C_E	IE	C_E
0	∞	.7	814	10	57	570	1.00
.2	2850	.9	633	57	10	900	.63
.5	1140	1.0	570	100	5.70	1000	.57

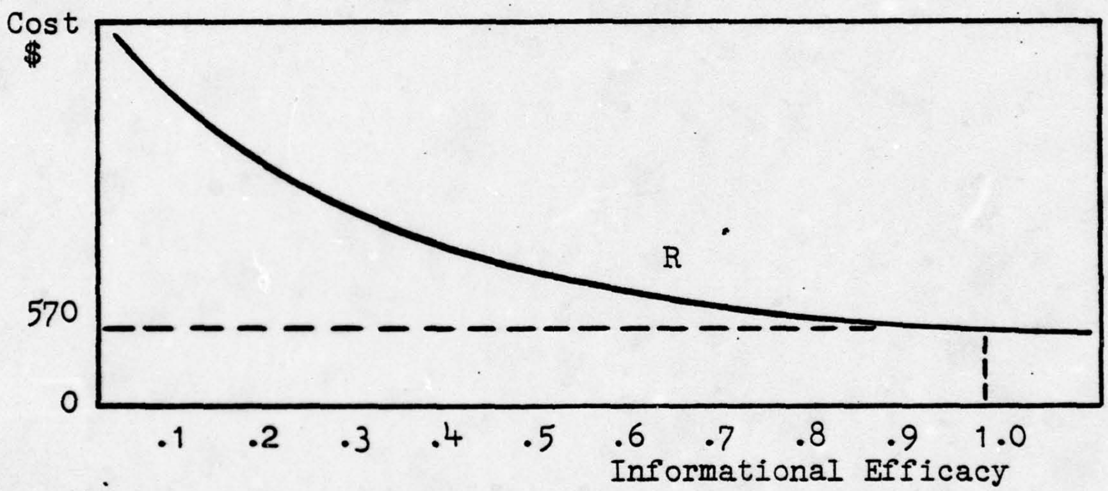

Fig. 17.--Cost-informational efficacy pattern

inadequate task definition. Assuming the existence of the probability distribution in Table 8, the expected cost can be calculated.

$$C_E = \frac{C_I}{1-H}$$

$$= \frac{570}{1-.4582}$$

$$= \frac{570}{.5418}$$

$$= \$1,052.$$

If in fact the program was negotiated at a cost of \$570, a cost growth of \$482 could occur. The change would reflect an 85 percent increase in estimated cost. The probability distribution in Table 9 is more leptokurtic in shape. The .95 value reflects a high degree of belief in the one estimate. On this basis, C_E would be \$639. The value would reflect an increase in costs of 12 percent.

Technical changes were considered to be the prime cause of cost growths.[12] The model deals with this causative variable in terms of the uncertainty factor in the denominator. The next factor contributing to cost growths was inflation. This economic variable can be incorporated into the model in the numerator.[13] Assume that inflation is represented by the symbol rho, p, then

$$C_E = \frac{C_I p}{1-H}$$

If inflation of 5 percent per year is anticipated, then the expected cost value can be calculated. A two-year program is assumed. The entropy value is .1087. A compound interest factor can be substituted for the inflation

[12]"Defense Digest," Armed Forces Management, January, 1970, p. 17.

[13]James C. Van Horne, "A Note on Biases in Capital Budgeting Introduced by Inflation," Journal of Financial and Quantitative Analysis, VI (January, 1971), p. 656.

variable. This factor, 1.159, can be obtained from a Compound Interest Table.[14]

$$C_E = \frac{(1.05)^2\ 570}{1-.1087}$$

$$= \frac{(1.159)\ (570)}{.8913}$$

$$= \frac{660}{.8913}$$

$$= \$740.$$

Thus, under the postulated conditions, the program cost would be increased to $740 for the total two-year period. The amount would absorb the [illegible]t of inflation and technical changes. Possible constraints by both parties to prevent a cost growth based on technical changes are ignored.

The Cost of Informational Efficacy

The relationship of informational efficacy and program cost is illustrated in Figure 17, page 128. As the level of informational efficacy increases, the costs for the developmental program decrease. Ostensibly, the logical approach is to continuously expand informational efficacy. In this manner, program costs can be reduced to a nominal amount. Costs will not fall to zero, since the curve is asymptotic to the abscissa. This course of action would be optimal if informational efficacy was a free good. However,

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[14]J. Fred Weston and Eugene F. Brigham, Managerial Finance (3rd ed.; New York: Holt, Rinehard, and Winston, 1969), p. 816.

the upgrading and maintenance of informational content have a definite cost. The management information system has fixed costs which accrue from the system's existence. The computer must be energized, air conditioned, and maintained. Personnel salaries are relatively fixed, regardless of the state of the information in the system. The variable costs for the system have two primary components. Up to some point, additional amounts of information are needed; and secondly, the informational efficacy of the information units needs to be increased and maintained. On the basis of historical cost relationships, the assumption can be made that the total cost of acquiring, maintaining, and transmitting the information can be expressed by the equation:

$$C_A = ae^{bt}$$

where C_A stands for the total cost of informational efficacy; a for the fixed costs of the system, e for the expression $(1 + h)^{1/h}$, b for the growth rate, and t for the time variable. The symbol e is the base of the natural logarithms.[15] The formula is an exponential function which exhibits growth over time.[16] The assumption can be made that a multiple regression analysis has been performed, using historical cost

[15]Jean E. Draper and Jane S. Klingman, Mathematical Analysis (New York: Harper & Row, Publishers, 1967), p. 105.

[16]Sherman K. Stein, Calculus for the Natural and Social Sciences (New York: McGraw-Hill Book Company, 1968), pp. 109-112.

data for the informational system under consideration.[17] The result is a \$542 value for a, .5 for b, 2.718 for e, and t can assume theoretically a range of values from zero to infinity. For these values, the cost of informational efficacy can be computed for a given system configuration. (See Table 11.)

TABLE 11

COST OF INFORMATIONAL EFFICACY

t	C_A	t	C_A
0	\$542	2	\$1,473
1	894	4	4,005

The data in Table 11 have been plotted in Figure 18. An examination of the curve in Figure 18 reveals that the cost for informational efficacy increases at an increasing rate. This cost is essentially the price of program administration.

Total Economic Cost

Ideally, the total cost for the government is minimal for a specific program. Conceptually, the total cost is the cost of the developmental program plus the cost of program administration. The cost trends for the two components are

[17]Frederick E. Croxton and Dudley J. Cowden, Applied General Statistics (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1955), pp. 534-551.

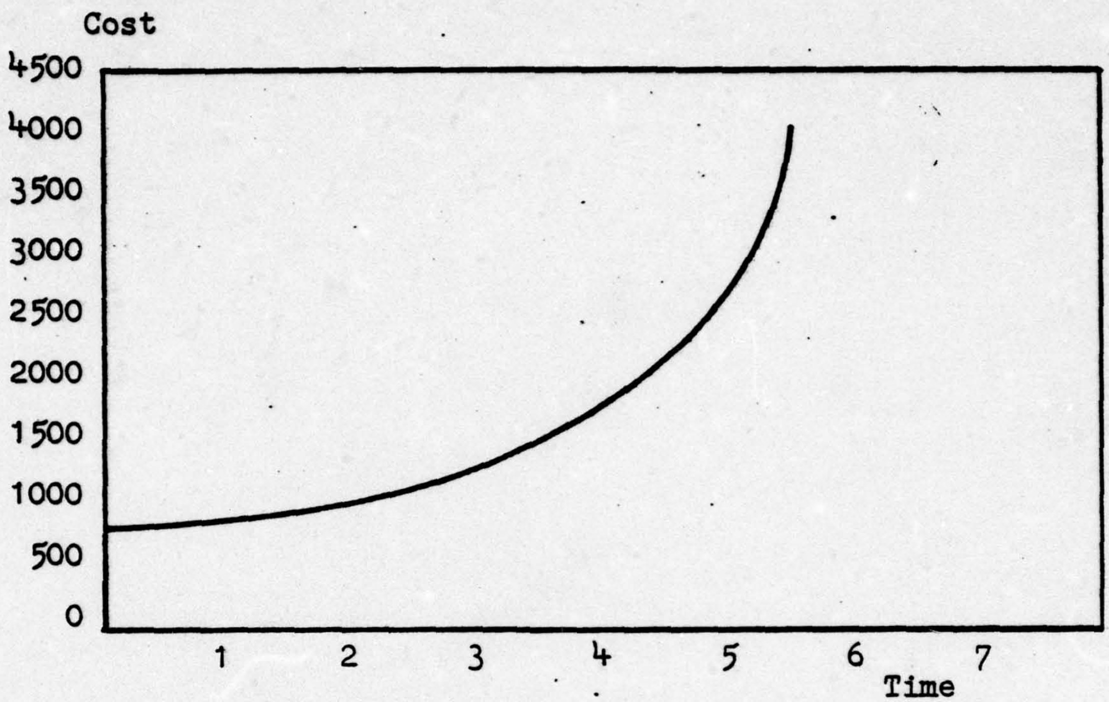

Fig. 18.--The cost of informational efficacy

divergent. For program administration, the cost relationship can be expressed by the formula:

$$C_A = ae^{bt}$$

The formula is the exponential growth function. The pattern is for costs to increase at an increasing rate.

As derived for economic program cost, the relationship is expressed by the formula:

$$C_E = \frac{C_I}{IE}$$

When informational efficacy increases, program costs decrease. A decrease in informational efficacy is attended by an increase in program costs. The relationship between informational efficacy and time is a direct one. Uncertainty is

the connecting link. The resolution of uncertainty over time is accompanied by an increase in informational efficacy. The required conditions of the relationship can be approximated by the exponential decay function:

$$C_E = de^{-gt}$$

where C_E stands for the economic program cost, d for the maximum expected economic program cost, e for the base of the natural logarithms, g for the decay rate, and t for the time variable.

Therefore, total economic cost can be expressed by the formula:

$$C_{TC} = C_A + C_E \quad .$$

where C_{TC} stands for total economic cost. Substitution in the formula for C_A and C_E transforms the equation:

$$C_{TC} = ae^{bt} + de^{-gt}$$

Differentiation of this function with respect to time will give the first derivative of the total economic cost:

$$\frac{\partial C_{TC}}{\partial t} = abe^{bt} - gde^{-gt}$$

Setting the function equal to zero will give the minimal point for total economic cost:

$$abe^{bt} - gde^{-gt} = 0$$

The solution under the conditions as posited is 2. The value can be checked by substituting the assumed numbers in the equation:

$$(542)(.5)(2.718)^{(.5)(2)} - (4{,}000)(.5)(2.718)^{-(.5)(2)} =$$

$$(271)(2.718)^{1} - (2{,}000)(2.718)^{-1} =$$

$$(271)(2.718) - (2{,}000)(.368) =$$

$$736 - 736 = 0$$

The numerical values for e^1 and e^{-1} are from a Table of constants.[18]

The second partial derivative with respect to t can be computed:

$$\frac{\partial^2 C_{TC}}{\partial t^2} = ab^2 e^{bt} + dg^2 e^{-gt}$$

If the total economic cost curve is at a minimum when t equals 2, then the second partial derivative will have a positive value. The result of this computation is a positive value. The selected economic program costs for several values of t have been listed in Table 12. The figures in Table 12 have been plotted in Figure 19 to give the economic-program-cost curve. Also the data in Table 11 for the informational-efficacy-cost curve have been plotted. Curve C represents the cost curve for the total program cost. At t equals 2 the total cost curve is at a minimum. The minimum point on curve C occurs at Y. Point X on the axis is the optimal cost. The minimal point also occurs at the point where the economic-program-cost curve, B, and the

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[18]Kaj L. Nielsen, College Mathematics (New York: Barnes & Noble, Inc., 1958), p. 279.

informational-efficacy-cost curve, A, intersect, point D. Thus, for an anticipated level of negentropy the optimal over-all cost has been determined.

TABLE 12

ECONOMIC PROGRAM COST

t	C_A	t	C_A
0	$4,000	2	$1,480
1	2,424	4	540

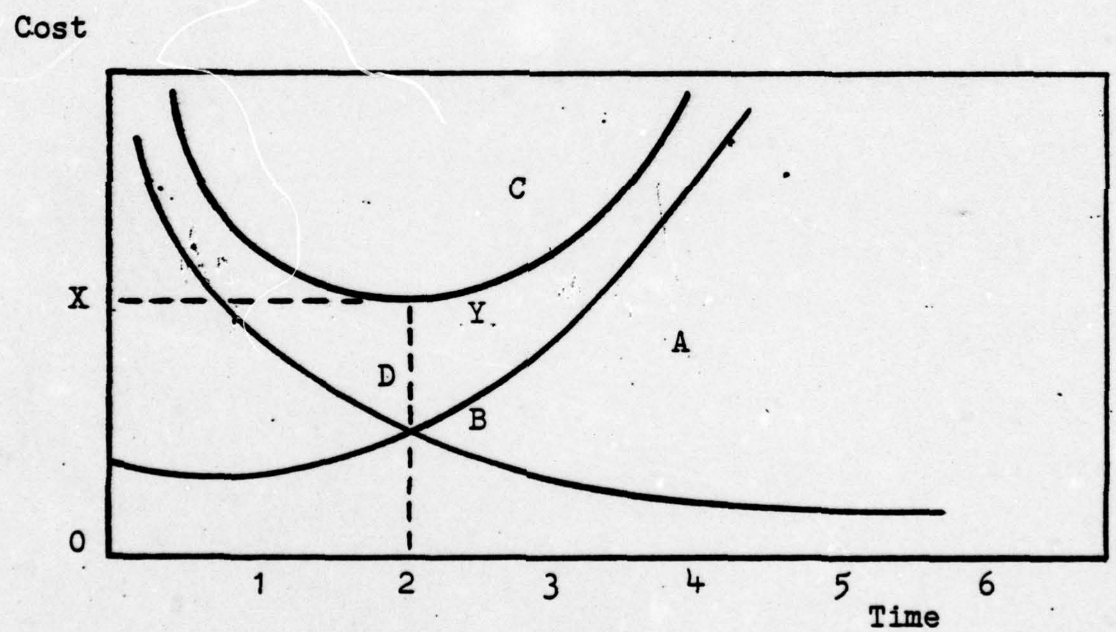

Fig. 19.--Total economic program cost

The Management Information System

The conceptual cost model emphasizes the importance of the management information system to contract administration. Suboptimal decisions can occur, if the economic

program cost is considered in isolation. Rather, the total-cost approach is the touchstone. Only in this manner can optimal decisions be assured. The total-system approach dictates that total economic cost will be minimized. In this context, a cost growth may be warranted, if the over-all cost will be at a minimum. However, an impending cost growth must be detected before such a decision can be made.

The key role of the management information system is to provide proper cost visibility. The decision maker may have to alter his decision after the receipt of new information, possessing a high degree of informational efficacy. Changes in the conditions surrounding the developmental program will supply evidence of possible deviations. The information system must be designed and constructed to detect and report possible incipient disruptive factors. These incipient variables must be defined, categorized, and their possible impact ascertained.[19] The identification of trends and patterns needs to be accentuated. For example, in Table 5, page 88, engineering changes are listed as a cause of contractual cost growths. A pattern of increasing and diffuse engineering changes should alert the program manager. He must completely analyze the total program as related to the totality of the changes being made, and not just examine

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[19] D. DiSalvo, G. R. Hall, A. J. Harman, G. S. Levenson, R. L. Perry, G. K. Smith, and J. P. Stucker, System Acquisition Experience (Santa Monica, California: The RAND Corporation, November, 1969), p. 39.

each one in a vacuum. A knowledge of the factors which have contributed to cost growths in the past will enable the decision maker to recognize and detect program-change trends. Another need for the information system is the rapid delivery of high-fidelity information to the decision maker.[20] As mentioned previously, some organizations require a detailed management information report every thirty days. The delays involved can contribute to the magnification of problems. An undetected problem which has been expanding for five or six weeks may be difficult to control. Significant information must be timely and accurate. If performance ratings for personnel are predicated on certain workload indicators, this condition can lead to falsification of statistics to meet some arbitrarily established standard.[21] The reporting system must enhance cost visibility.[22] The visibility depends on an effective management information system abetted by frequent independent reviews and analyses. Visibility can be enhanced by engagement with the contractor, especially for large-dollar programs. The monitoring of programs may utilize management science techniques. For

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[20] F. S. Timson, Technical Uncertainty, Expected Contract Payoff, and Engineering Decisionmaking in a System Development Project (Santa Monica, California: The RAND Corporation, August, 1970), p. 83.

[21] David Halberstam, "The Programming of Robert McNamara," Harper's Magazine, February, 1971, p. 60.

[22] Edgar Ulsamer, "The Accent is on Flying," Air Force Magazine, June, 1971, pp. 26-27.

example, the milestone approach might be adopted. The program would be divided into small manageable steps. Technical progress and cost control would be examined at periodic intervals.

These needs emphasize the imperative nature of an effective management information system. Wiener,[23] Wofsey,[24] and Wendler,[25] discuss the requirements for an efficacious system. However, Schumacher does so in a more succinct and concise manner.[26] His enumeration will be considered.

Anthropocentricism.--The system must be oriented to the user and the input agent, and not to a hardware component, such as a central or peripheral computer. The interface points between the computer and decision maker and the input agent and computer sensors should be the design focus. The facilitation of these interactions is the primary objective.

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[23]Wiener, op. cit., pp. 11-14.

[24]Marvin M. Wofsey, Management of Automatic Data Processing Systems (Washington, D.C.: Thompson Book Company, 1968), p. 76.

[25]Clifford Wendler, "What Are the Earmarks of Effective Total Systems?" Systems and Procedures Journal, 17 (July-August, 1966), pp. 20-30.

[26]B. G. Schumacher, Computer Dynamics in Public Administration (Washington, D.C.: Spartan Books, 1967), pp. 57-59.

Flexibility.--Environmental change is a constant occurrence. The system design must enhance detection and adaptability to change. If the system is automated, the computer may be programmed to exhibit flexibility by the use of heuristics. Early detection of abnormal deviations is essential.

Generality.--The system must be total in scope. The factor encompasses the requirement for integration and organization. Increasing complexity and disorder tend to degrade the system. Complexity can be a derivation of size. The larger the organization, and the more dispersed its parts, the greater is the diffusion of information in the environment. Bonner posits a direct relationship between size and complexity factors.[27] Complexity involves a magnification of detail and a diffuse pattern of activity. For detail, the lowest common denominator must be identified. This action will permit functional modularity in design. Functional modularity allows the changing of the basic system components to meet specific needs as stimulated by change.

Simplicity.--Ideally, the system is tailored to its organizational environment. The total man-machine configuration and the size of the user group are factors to consider.

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[27] John T. Bonner, "The Size of Life," Natural History, January, 1969, pp. 40-45.

Simplicity of design is necessary to avoid hysteresis loss of valid data.

Dynamic Model Aspects

The assumption that organizational homeostasis is synonomous with the maintenance of the optimal total economic cost can be made. Then, the objective of a funds expenditure for contracts and program administration is to keep the organization at the lowest point on an aggregative total economic cost curve.

As indicated, the purpose of the conceptual cost model is to obtain a better understanding of the nature of the cost-growth process. The key concepts are those of entropy and its relationship to uncertainty. The program-cost outcome depends on the subjective evaluation of the past and current environments and their projection into the future. The derivation of a probability distribution will be affected by the individual's preference function as related to risk. The individual expresses his degree of confidence as to the future occurrence of some particular event or sequence of events.[28] The result at t_0, for a given program, is an array of possible probability distributions. (See Figure 8, page 51.) As Schumpeter asserts, analysis which deals with the relationships between variables for a given point in

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[28] A. J. Ayer, "Chance," Scientific American, October, 1965, p. 44.

time is static.[29] The model can assume dynamic overtones, if past and future values of variables, lags, sequences, rates of change, cumulative magnitudes, and expectations are incorporated.

A computer program may be developed to simulate the contract administration process, as reflected by the conceptual cost model. The parameters of time, cost, uncertainty, entropy, and informational efficacy may be manipulated to simulate various world states. An iterative routine would test each alternative economic cost for several probability distributions.[30] Basically, simulation permits the identification of successive states of the situation by the repetitive application of the rules that govern a system.[31] A knowledge of possible outcomes and the network structure of the variables which contribute to the outcomes will enhance the probability of problem detection and identification.

Dynamic programming can be effective in maintaining the homeostasis of the organization.[32] The programming of

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[29]Joseph A. Schumpeter, History of Economic Analysis (New York: Oxford University Press, 1954), pp. 963-964.

[30]David B. Hertz, "Risk Analysis in Capital Investment," Harvard Business Review, January-February, 1964, pp. 99-104.

[31]*Clifford Springer*, Robert E. Herlihy, and Robert I. Beggs, Advanced Methods and Models (Homewood, Illinois: Richard D. Irwin, Inc., 1965), p. 173.

[32]Harold Sackman, Computers, System Science, and Evolving Society (New York: John Wiley & Sons, Inc., 1967), p. 607.

the central computer which controls the management information system is structured to permit the computer to react automatically to the occurrence of seemingly random cost deviations. Corrections are made, when possible, and the decision maker notified. The method is based on Bellman's Principle of Optimality.[33] The process is sequential and its objective is to maintain the integrity of the predefined objective function of the system. In contract administration the goal is the minimization of the total economic cost for a developmental program. The totally automated information system does not yet exist. However, the incorporation of a dynamic algorithm in the information system to cybernetically adjust to all threatening environmental changes is utopian in concept, but is a worthwhile goal.

The Significance of the Model

A mathematical function, such as $y = x^2$, is determinant and certain. For a given value of x only one value of y can occur. For example, if x is equal to 2, then y is equal to 4. The conceptual cost model is not of this nature. The relevant variables are large in number, and the nexus is complex. Essentially, no magic number can be derived for the future cost of a program. The best estimate will still intrinsically incorporate an indeterminate measure of

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[33] U.S., Department of the Army, U.S. Army Management School, Operations Research/Systems Analysis Executive Course, GEN-1.2 (Fort Belvoir, Virginia: U.S. Army Management School, May, 1968), p. 9.

uncertainty. The value of the model relates to its explanatory capabilities. It illustrates the relationship between program cost and the disorder in a contract administration system.[34] The purpose of the management information system is to essentially help alleviate this disorder condition. Increasing disorder will give increasing program costs. The disorder or noise is created by warp factors in the current and future environments. The objective is to better understand cost growths and their causes. From a total system frame of reference, not all cost growths are detrimental. In some cases, over-all welfare can be enhanced, if total economic cost is reduced. Informational efficacy is necessary for optimal and effective decisions. However, additional increments of information are warranted, provided the marginal return is equal to, or exceeds, the marginal cost of increased informational efficacy. The inverse of a cost growth can occur. A cost underrun normally develops when costs are lowered by some technological breakthrough, so that production costs are reduced, or by the program not being conducted at the planned level.

In developing the model, simplicity was the guiding principle. Based on his experience, Einstein believed that nature was the realization of the simplest conceivable

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[34]Myron Tribus and Edward C. McIrvine, "Energy and Information," Scientific American, September, 1971, p. 179.

mathematical ideas.[35] Complexity can obscure details and the true nature of a system. However, the simplest idea is basically a first approximation. A conceptual paradigm must be validated or refuted by empirical research.[36] In the early decades of this century attempts were made by Hilbert, Russell, and other mathematicians, to create a system within which the whole of mathematical theory could be developed.[37] Four characteristics were stipulated: (1) no contradictions could occur, (2) the system would be logically complete, (3) its principles would be conceptually universal, and (4) the system would be formal. However, in 1931, Kurt Godel demonstrated that such a system was unattainable. This theory stipulates that every system must fail in at least one of three ways which can be summarized as follows: (1) The system will contain a basic contradiction, (2) Questions exist which the system can ask, but cannot answer, (3) The structure of the system will be too weak to comprehend the most elementary details. Thus, increasing complexity can cause degradation by factors, such as the incorporation of anomalies in the basic structure of the system, excessive

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[35] Martin Gardner, "Mathematical Games," Scientific American (August, 1969), pp. 118-119.

[36] J. Fred Weston, The Scope and Methodology of Finance (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1966), pp. 42-43.

[37] A. S. Davis, Godel's Theorem (Norman, Oklahoma: Department of Mathematics, The University of Oklahoma, 1964), pp. 1-8.

information in the data banks, the storage of incomplete information, and the creation of decision situations which have no basis in reality.

Testing the Assumptions of the Model

The logical consistency of the assumptions which have been posited for the conceptual cost model can be checked by means of symbolic logic.[38] The assumption is that entropy implies uncertainty, that information implies entropy, and these two statements imply information which implies uncertainty. Information is defined as the number of choices available to the decision maker, or the number of events which could occur. If entropy is increased under these assumptions, then information should increase, as well as uncertainty. Let c be entropy, a be uncertainty, and o be information, then is the statement, $[(c \rightarrow a) \rightarrow (o \rightarrow c)] \rightarrow (o \rightarrow a)$ true? The statement is examined in Table 13, where T equals true and F equals false. An examination of the final column in the Table reveals that the statement is true. Thus, the assumptions as outlined and related are logically consistent.

[38] John G. Kemeny, *et al*., *Finite Mathematics* (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1962), pp. 1-18.

TABLE 13

LOGIC TEST FOR ASSUMPTIONS

c	o	a	$(c \rightarrow a)$	$(o \rightarrow c)$	$[(c \rightarrow a) \wedge (o \rightarrow c)]$	$(o \rightarrow a)$	$[(c \rightarrow a) \wedge (o \rightarrow c)] \rightarrow (o \rightarrow a)$
T	T	T	T	T	T	T	T
T	T	F	F	T	F	F	T
T	F	T	T	T	T	T	T
T	F	F	F	T	F	T	T
F	T	T	T	F	F	T	T
F	T	F	T	F	F	F	T
F	F	T	T	F	F	T	T
F	F	F	T	F	F	T	T

CHAPTER X

COST UNCERTAINTY ANALYSIS METHODOLOGY

In Chapter IX, the emphasis was primarily on the over-all contract administration segment of the procurement life cycle. The following conceptual cost model was developed:

$$C_E = \frac{C_I}{IE} \quad .$$

A value for C_I, the initial expected economic cost, was assumed. This Chapter is concerned with the methodology for evaluation of C_I estimates for developmental programs. At present, the process is referred to generally as cost analysis. It has been defined as a detailed analysis of the elements which are contained in a prospective contractor's cost proposal. In response to the need for a methodology to identify and control the risks associated with major developmental programs, risk analysis has evolved.[1] Risk analysis can be defined as a scientific approach for the

[1] James L. Arnett, A Program of Instruction for Risk Analysis (Fort Lee, Virginia: School of Logistics Science, U.S. Army Logistics Management Center, undated), p. 1.

evaluation of the uncertainty associated with a developmental program or system. The uncertainty may be related to cost, time, or performance goals. The cost analysis may be associated with systems or the individual programs which comprise systems.[2] The emphasis is on cost analysis for individual contracts. In general, the principles espoused for one are applicable to the other. The preparation and evaluation of cost estimates to a degree is an art, rather than a science.[3] However, management and financial science techniques may aid the decision maker in the process of orderly and logical thinking. Pardee asserts that the uncertainties which relate to cost, time, and performance cannot be accommodated by using traditional statistical and probability techniques.[4] Insofar as the reference is to objectivistic or classical probability theory, the statement is valid. In classical probability theory, the concept of equally likely is stressed.[5] For example, the probability of obtaining a tail on one flip of a fair coin would be equal to .5. This value is computed as a ratio of favorable cases to the total

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[2]James D. McCullough, "Estimating Systems Costs," in Cost-Effectiveness Analysis, ed. by Thomas A. Goldman (New York: Frederick A. Praeger, Publishers, 1967), pp. 69-89.

[3]Ibid., p. 70.

[4]F. S. Pardee, Guidelines in Accumulating Financial Data on Future Weapons (Santa Monica, California: The RAND Corporation, May 27, 1960), p. 13.

[5]Howard Raiffa, Decision Analysis (Reading, Massachusetts: Addison-Wesley, 1968), pp. 273-275.

number of equally likely cases. In the example, one divided by two equals .5. Glennan insists that no amount of analysis can eliminate program uncertainties.[6] Again to a point the statement is substantive. The objective is to reduce uncertainty, rather than its complete elimination. Instead of classical probability theory, Bayesian statistics will be used in this chapter. The theorems of the probability calculus will hold. The difference is subjective as opposed to objective probabilities. Consequently, actual results, after validation by time, will not always be in agreement with a priori probabilities. The focus in subsequent sections will be on the evaluation of C_I, the initial estimated economic cost.

Cost Element Estimation

Proposals submitted by contractors usually include a technical program outline and a cost budget for activation of the effort. If the program is to be placed by multiple-source solicitation, the military agency can evaluate the technical proposal and its budget. In this way an independent cost estimate will be derived. The estimate may be used as the touchstone to measure the validity of the cost estimates submitted in response to the request-for-proposal. Should the program be sole source, the approach can still be used.

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[6]Thomas K. Glennan, Jr., An Economist Looks at R&D Management (Santa Monica, California: The RAND Corporation, November, 1963), p. 4.

The individual agency may evaluate the technical proposal without reference to the contractor's budget, and then develop their independent estimate of what the program ought to cost. At this juncture, an assessment of the individual risks and uncertainties can be accomplished.[7] The possible extra costs which stem from the anticipated exogenous and endogenous, and the unanticipated exogenous and endogenous uncertainties would be incorporated into the estimating process. Three primary techniques are used to develop cost estimates.[8]

Industrial engineering.--In this approach, the individual elements are evaluated at a low level of detail. The elements are then aggregated to derive a total. Engineering standards for various operations are necessary. For example, the item being costed might be the job of shaping basic metal stock, using a lathe, into a component part for an aircraft engine. The standard times are aggregated, and the total is costed to arrive at a cost estimate. The data necessary for this approach are usually not available to government personnel.[9] Additionally, the process is

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[7]Richard M. Anderson, "Handling Risk in Defense Contracting," Harvard Business Review, July-August, 1969, p. 92.

[8]C. A. Batchelder, et al., An Introduction to Equipment Cost Estimating (Santa Monica, California: The RAND Corporation, December, 1969), pp. v-vi and 1-10.

[9]Ibid., p. 7.

extremely time consuming, and the estimates have been found to be less accurate than those formulated statistically.

Statistical approach.--The cost estimates are computed, using estimating relationships for variables, such as weight, speed, and range. A decreased level of detail is involved. Instead of working with individual jobs to develop costs, the over-all category is used. For example, in the engineering approach, the various types of labor hours would be evaluated, then summed. For the statistical approach, the generic category labor hours is used. As in the previous approach, historical data serves as the basis for cost estimates. In the statistical approach, regression coefficients are calculated and used to predict future estimates.

Analogy.--Estimating by analogy is a rather crude process. If system A originally cost $1,000, and system B is identical, except for contemplated cost increases of 10 percent, then system B will cost $1,100. The analogy procedure requires the exercise of more judgment than the other techniques. The key is to determine how much the program under consideration resembles past programs.

For most situations, statistical procedures are preferred.[10] This preference accrues primarily from the flexibility and general applicability of the approach. Regression analysis, both single and multiple, is the main tool used.

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[10] Ibid., p. 7.

In terms of cost, historical data are examined to identify variables related to cost. The relationship may be tested for significance. For example, if cost is the dependent variable in a regression analysis for an aircraft, the relationship of weight and speed to cost might be examined. If speed is increased, what impact does this change have on cost? If a definite relationship is established, changes in the two independent variables will be associated with changes in the dependent variable. However, the fact that the variables are related does not imply causality.[11]

A phenomenon which may be important in cost analysis is the 80-20 Rule.[12] The principle derives from the fact that a small percent of one variable accounts for a large percent of another one. Constantin reports studies where a small percentage of products account for a large percentage of company profits.[13] For example, 20 percent of the products in the product line could account for 80 percent of the profits for a firm. Should the company want to lower costs, it might be justified in eliminating one or more of the products that account for only 20 percent of profits. For government organizations, salaries and wages may be one of four or five budget categories. This 20-25 percent may

[11] Ibid., p. 56.

[12] Clifford H. Springer, Robert E. Herlihy, and Robert I. Beggs, Basic Mathematics (Homewood, Illinois: Richard D. Irwin, Inc., 1965), p. 45.

[13] Constantin, op. cit., p. 36.

account for over 90 percent of the total organizational administrative cost. The principle has a wide range of applications. Patterns which fit the rule must be identified. Such actions may aid in cost analysis.

In aggregating individual cost components, the law of large numbers is often applicable. This law implies that the deviations from the mean of component costs will average out. The single event defies prediction, whereas, the mass remains essentially the same or can be predicted within limits.[14] The individual cost estimate is considered to be a sample from a larger population. Assuming normality and randomness, the inference is that the values will cluster around the universe mean in accordance with Chebycheff's Law.[15] The primary objective is to determine the total program cost. Individual components may vary from estimates, but the total will not fluctuate drastically.

Commoner asserts that the properties which a complex whole displays cannot be solely explained by the properties observed in isolated parts.[16] This paradoxical conclusion is referred to as the fallacy of composition. What is characteristic of an individual cost element will not necessarily

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[14]Hardy, op. cit., pp. 19-20.

[15]Ayer, op. cit., pp. 46-48.

[16]Barry Commoner, Science and Survival (New York: The Viking Press, 1967), p. 43.

be true for the whole.[17] The principle may be misleading in cost analysis. For example, a factor which degrades the accuracy of the industrial engineering approach to cost estimation, is that individual estimates are aggregated to deduce the whole.[18]

Cost Uncertainty Analysis

Cost analysis and risk analysis have already been defined. Arnett considers risk analysis to be essentially systems analysis with the added feature of uncertainty.[19] However, in the cost area, Sutherland addresses the subject directly for a given program.[20] His approach envisions uncertainty being evaluated at the aggregate level. However, for a large system the cost analysis might be conducted at the next lower generic cost level, such as recurring and non-recurring costs. Also, subdivisions, such as labor hours, materials and supplies, and equipment might be germane. He concludes that each aggregate cost estimate should include a section which evaluates cost uncertainties. Sutherland's approach will be adopted. The assumption is made that the cost estimates used in subsequent paragraphs are based on regression studies. Each estimate so derived will have been

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[17]Paul A. Samuelson, Economics (6th ed.; New York: McGraw-Hill Book Company, 1964), p. 11.

[18]Batchelder, op. cit., p. 5.

[19]Arnett, op. cit., p. 4.

[20]Sutherland, op. cit., pp. 7-8.

adjusted in an experiential manner based on an evaluation of qualitative factors associated with the regression study.[21] The selection of the economic program cost most likely to occur for a developmental program requires decisions to be made. Decision trees are graphic management-science tools which may aid contracting personnel in the decision-making process.

Decision trees.--Pending negotiations require the government manager to take action. He must decide whether or not to select a specific estimated economic program cost as his goal. Overt action is required. An act may be defined as a decision by the individual to take a definite course of action.[22] If the assumption is made that A = $\{a_i\}$ set of actions, then a decision is defined as the selection by the decision maker of one element from set A.[23] In cost analysis A represents the possible cost estimates which might be selected for a given contract. An event may be defined as a subset of a sample space.[24] Acts are under the control of

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[21]Norman V. Breckner and Joseph W. Noah, "Costing of Systems," in Defense Management, ed. by Stephen Enke (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1967), p. 55.

[22]Robert Schlaifer, Probability and Statistics for Business Decisions (New York: McGraw-Hill Book Company, Inc., 1959), pp. 3-24.

[23]Hwang, op. cit., p. 18.

[24]T. R. Dyckman, S. Smidt, and A. K. McAdams, Management Decision Making Under Uncertainty (London: The MacMillan Company, 1969), p. 34.

the individual; the possible outcomes or events are uncertain and beyond the decision maker's control. A process of change, where the decision maker is faced with more than one outcome, is uncertain and is called a stochastic or random process.[25] The acts available to the manager can be illustrated by a decision tree.[26] This device is a graphical-sequential technique for portraying the act-event sequence.[27] A decision tree is diagrammed in Figure 20. An act would be to select either Program A or B. The event success would be applicable if the cost estimate was accurate or an underrun occurred, and no success would imply that a cost growth was the outcome.

Probability assignments.--The assumption can be made that historical cost data has been analyzed. This review shows that Program A has been selected with a frequency such that a .5 probability is assigned. (See Chapter V, pages 53 through 56.) The same probability is assigned to Program B. The probability of success when A was chosen has been .7 and for B the figure is .5. In Figure 21, these probabilities have been added to the decision tree. The question arises, what is the unconditional probability of success for expected

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[25]Hwang, op. cit., p. 18.

[26]L. S. Hill, Management Planning and Control of Research and Technology Projects (Santa Monica, California: The RAND Corporation, June, 1966), p. 49.

[27]John F. Magee, "Decision Trees for Decision Making," Harvard Business Review, July-August, 1964.

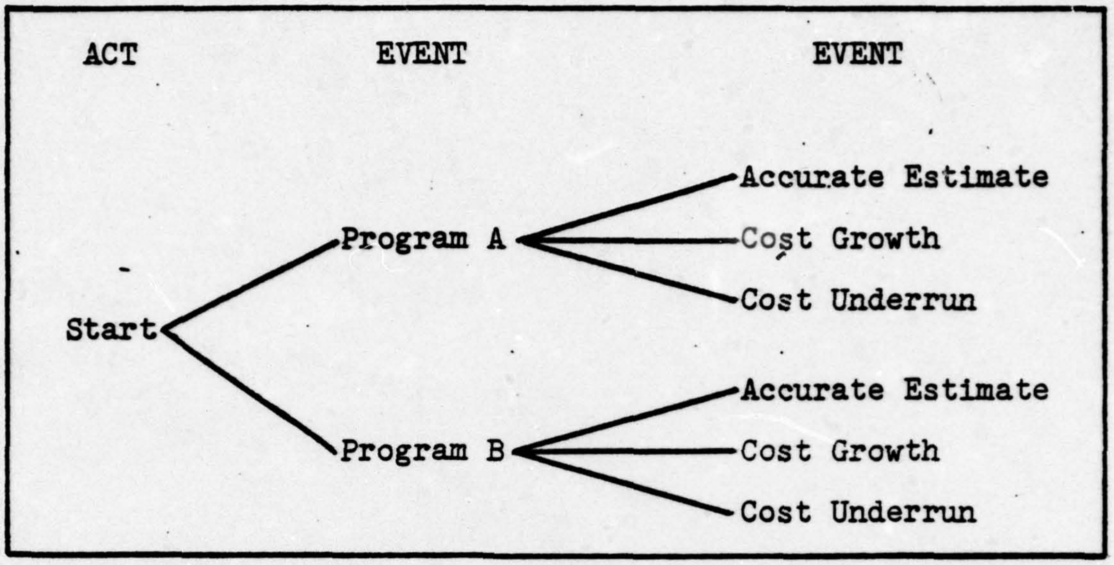

Fig. 20.--Decision tree for two programs

cost A? The question relates to the occurrence of joint events. For example, A occurs and so does success. The joint probability is (.5)(.3) = .15, plus (.5)(.4) = .20 for a total of .35. Joint probabilities have been added to the decision tree in Figure 21. The unconditional probability of success is .25 + .35 = .60. The conditional decision tree with assigned probabilities is a very useful decision tool and will be used again in a latter section.[28]

Utility theory.--The concept envisions that a quantitative scale can be derived which describes an individual's preference for various degrees of risk.[29] (See Chapter V,

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[28]Clifford H. Springer, et al., Probabilistic Models (Homewood, Illinois: Richard D. Irwin, Inc., 1968), pp. 225-229.

[29]Grayson, op. cit., pp. 114-118.

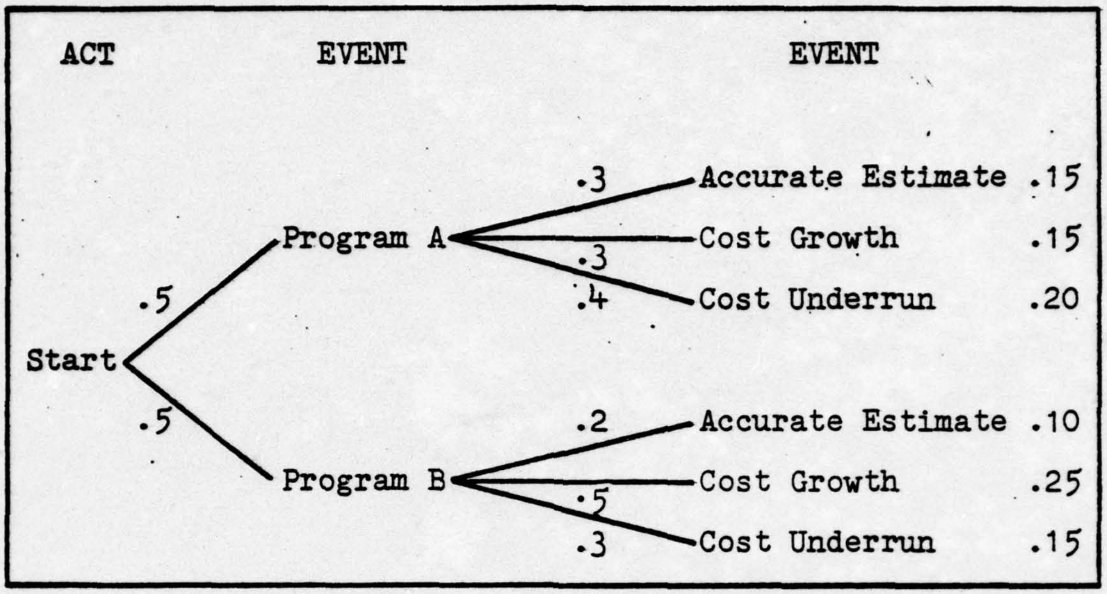

Fig. 21.--Decision tree with assigned probabilities

pages 56 through 61.) Depending on the over-all shape of his utility function, an individual can be classified as a risk averter, risk seeker, or a risk ignorer. The utility function may aid in decision making.[30] From the above illustration, the expected economic cost for Program A is $57,000. (See Table 2, page 54.) For Program B, the expected economic cost is $60,500., as computed in Table 14. Then Tables 2 and 14 show the situation prior to the application of utilities. Program A is superior to B, having an expected economic cost of $57,000. The utility function for the agency (derived from an entire group of managers who

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[30] J. R. Miller, III, A Systematic Procedure for Assessing the Worth of Complex Alternatives (Bedford, Massachusetts: The Mitre Corporation, November, 1967), pp. 28-29.

have responded to a posited lottery) is assumed. The utility values are weighed by the probabilities as in Table 15. The expected utility value of 5.0 for Program B is higher than the 4.0 value for A. Thus, the choice is B, rather than A, when risk preference is considered.

TABLE 14

EXPECTED COST FOR PROGRAM B

Expected Cost	Probability	Expected Value
$50,000	.4	$20,000
65,000	.3	19,500
70,000	.3	21,000
	1.0	$60,500

TABLE 15

EXPECTED UTILITY VALUE (EUV)

Program A			Program B		
Utiles	Probability	EUV	Utiles	Probability	EUV
8	.4	3.2	20	.4	8.0
6	.4	2.4	2	.3	.6
-8	.2	-1.6	-12	.3	-3.6
	1.0	4.0		1.0	5.0

Application of Bayes' Theorem.--New information which reduces the degree of uncertainty will often lead to

the revision of probabilities and permit the individual to modify his previous decision.[31] In the situation diagrammed in Figure 21, the unconditional probability of success was computed as .60. Suppose information is received which discloses that Program A will be selected, what is the probability of success, given this additional information? The probability can be computed using the following formula:

$$P(A_i \mid X) = \frac{P_o(A_i)\ P(X \mid A_i)}{\sum_j P_o(A_j)\ P(X \mid A_j)}$$

where the A_i's are a set of mutually exclusive and exhaustive events, $P_o(A_i)$ is the prior probability of A_i, X is the observed event, and $P(X \mid A_i)$ is the probability of the observed event given that A_i is true.[32] The formula is referred to as Bayes' Theorem. In reality, the formula is nothing more than the mathematical definition of conditional probability. Initially, prior probabilities that a given event will occur are stated, such as a striped ball being drawn from an urn with a probability of .5.[33] If a striped ball is drawn, the probability of red is .2. Thus, the joint probability of striped and red is .1; i.e., P(S,R) = (.5)(.2) = .1. The other balls in the urn are green-dotted, green-striped, and

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[31] John F. Magee, "How to Use Decision Trees in Capital Investment," Harvard Business Review, September-October, 1964, pp. 93-96.

[32] Schmitt, op. cit., p. 65.

[33] Schlaifer, op. cit., pp. 160-169.

red-dotted. Thus, if a ball is drawn, and it is red, this event provides new information. This occurrence may be used to revise the prior probabilities by the application of the conditional probability and Bayes' Formula:

$$P(S \mid R) = \frac{P(S,R)}{P(R)} = \frac{P(S)\ P(R \mid S)}{P(S)\ P(R \mid S) + P(D)\ P(R \mid D)}$$

Bayes' Formula is applied to the urn example in Table 16. The probability of a striped ball, given red is drawn, is sought. The new information that the ball which was drawn was red has permitted the probability of a striped ball to be revised from .6 (prior probability) to .33 (posterior probability). For the two-program example from Figure 21, the methodology is applied in Table 17. The unconditional probability of a cost growth is .40. The new information that A has been selected changes the probability of a cost growth from .40 to .375. Thus, the independent derivation of economic program cost estimates may be used to compute the likelihood of a cost growth. Continuous screening of environmental information is important. An evaluation of feedback data may reveal facts which permit the revision of initial probabilities. Efforts, such as those considered in this Chapter, may contribute to the reduction and resolution of cost uncertainties in government contracting.

TABLE 16

REVISION OF PROBABILITIES

Event	P(E)	P(R|E)	P(E,R)	P(E|R)
Striped Ball	.6	.2	.12	.12/.35 = .33
Dotted Ball	.4	.6	.24	.24/.36 = .67
	1.0		.36	1.00

TABLE 17

REVISED PROBABILITY OF A COST GROWTH

Event	Probability	Event P(Cost Growth)	Joint Prob.	Posterior Prob.
A	.5	.3	.15	.375
B	.5	.5	.25	.675
	1.0		.40	1.000

CHAPTER XI

CONCLUSIONS

In recent years much attention has been placed on the subject of cost growths. Uncertainties exist relative to program costs, delivery dates, and product reliability. Delivery schedules and reliability are directly related to costs. If a contractor is willing to expend unlimited funds, then the delivery schedule can be accomplished with the required degree of product quality. However, unlimited funds are not generally available. Thus, the need is for a conceptual cost model to assist the government and its contractors in coping with uncertainty parameters which could affect the costs of a sole-source, negotiated, developmental contract. The type of contract used to support a given program is at present the primary technique used to cope with cost uncertainty.

Environmental changes require weapon systems be modified to conform to the current technological state-of-the-art. The process leading from an idea to a system component or system may be thought of as a constantly evolving

spectrum. The continuum originates with the research stage and progresses through exploratory and advanced development to engineering development. The nature of the spectrum is dynamic. New ideas have their genesis at each stage of the spectrum, so the continuum is constantly being expanded. The research and development spectrum exists in an environment characterized by technological, cost, and other related uncertainties. The unknowns are greatest in the research stage, and decrease as a program passes across the spectrum. A monopolistic market relationship results from the high incidence of sole-source procurements. Thus, competition is not a stimulus which will regulate the formation of cost estimates. Instead, negotiations must attain the goal. Government procurements may be placed by either advertising or negotiation. Research and development programs seldom conform to the criteria for formal advertising. Thus, they are placed by means of negotiation.

The research and development continuum encompasses research, exploratory development, advanced development, and engineering development. With the addition of production and operational deployment, the total weapons acquisition process emerges. From a contractual standpoint, the weapon acquisition process can be segmented into four phases. These phases are concept formulation, contract definition, engineering development, and production and operation. From a historical perspective, the weapons acquisition process

evolved from a simplistic process effected in a simple environment to a complex procedure that has to be conducted in a highly-structured milieu. The military products evolved from general ones used by the majority to complex ones used only by a minority. The products are used in small quantities and must be manufactured by specialized firms. This factor gives rise to the need for the contractual relationship. At each interface between a procurement phase, a contract or contracts will be negotiated. Each contract will have a life cycle. The cycle is comprised of the steps, contractor proposal, requirement validation, procurement planning, contract negotiations, contract finalization, contract administration, and contract closure. Concerning cost uncertainties, two aspects of the procurement cycle are of signal importance. Cost growths occur over time during contract administration. However, factors considered when the contract was negotiated may cause cost variances. For procurement planning, a distinction must be made between cost and price analysis. Cost analysis envisions a detailed analysis of the elements contained in a prospective contractor's cost proposal. Evidence supports the contention that an unwarranted degree of confidence is placed in cost estimates. However, considering technical unknowns, and the possibility of environmental change, future cost variability is almost inevitable. The decision maker needs to insure that every effort will be made to reduce the cost uncertainties inherent in a given research and development program.

The structure of the defense industry has evolved based on implosive inputs of a political, social, and economic nature. The defense industry is composed of those firms which sell products and services either directly or indirectly to the Department of Defense. Many political, social, and economic factors have had a deterministic impact on the structure of the industry and accrue from the relationship between the Department of Defense and its contractors. The large number of sole-source, negotiated procurements would seem to validate a bilateral monopoly relationship. Economic forces interact to create a relationship that sets the defense industry apart from the general business community. Six basic interrelated factors comprise the economic forces: (1) absence of competition, (2) demand uncertainty, (3) geographical concentration, (4) production dependence, (5) industrial specialization, and (6) external and internal uncertainty. The political and social elements relate to the legal restrictions placed on the industry by the legislative and the judicial branches of the government. In the final analysis, the industry characteristics result from the nature of uncertainties or from the efforts that are taken to cope with them.

From a simplistic frame of reference, uncertainty is the absence of information. The uncertainty spectrum ranges from certainty with complete knowledge through risk with incomplete knowledge to uncertainty with the absence of

knowledge. Uncertainty and risk can be treated as synonomous terms. Various terms have been used to categorize and describe the type of uncertainties which have been identified and observed. The terms may be classified into four taxonomic classes: environmental, functional, informational, and technical. From these classes, a taxonomic definitional tree may be derived. In terms of the degree of knowledge present for a variable, uncertainties may be categorized as either anticipated or unanticipated. Each of these can be labelled relative to its origin. The terms, exogenous and endogenous were used. For example, unanticipated exogenous variables would be those external to the organization and unknown to the decision maker. In relation to the phases of the weapons acquisition process, uncertainty is resolved over time. As a scientific concept traverses the spectrum, information is gleaned from each stage which permits successful solution of the emergent problems. Information may be thought of as a commodity. In this sense, information may be described and measured. Information is the input commodity for a management information system. It should possess the characteristics of objectivity, validity, reliability, relevance, completeness, usefulness, organization, and recency. The degree of uncertainty present in a situation increases in direct proportion to the number of unknowns involved and the distance into the future of the contemplated events. Thus, uncertainty is a direct function of time. Change is a

constant in the environment. Change is predicated on time. Fluidity and movement characterize time. The goal is the reduction and resolution of uncertainty over time. Uncertainty can be eliminated either by taking definite action to reduce it or by transferring the risk to others. Thus, in the government-contracting relationship, uncertainty can be transferred to the contractor or the risk may be shared, and action taken by both parties to reduce its magnitude. Two measures of uncertainty can be used. First, probability can be used as a measure of uncertainty. Then, the probability distribution for a given random variable as related to the dispersion of values around the expected may be used to derive probabilities that a certain value of the variable will occur. Studies have shown that individuals exhibit varying attitudes toward risk. Cardinal utility theory may be used to measure an individual's attitude toward risk. Three categories of individuals relative to risk preference have been identified and labelled as risk averters, risk seekers, and risk ignorers. Individual utility theory has its bases in economic theory and is finding limited acceptance. However, the concept of a group utility function has not found as many advocates. The reduction and resolution of uncertainty can be expensive. The question is how much time and resources are the pertinent parties willing to pay for the reduction of uncertainty. As a rule, new information should be sought, so long as the marginal return exceeds, or is

equal to, the marginal cost of the effort. As startling as it may seem, a cost growth for a specific contract may be less costly than the actions which would have to be taken to preclude its occurrence.

The military services have attempted to cope with uncertainty by the use of incentives and contractual arrangements. Degree of risk bearing by contractors has been a key determinant of the profit allowed on an individual contract. Theoretically, the more uncertainty borne by the contractor, the larger the profit permitted. Tentative findings seem to indicate that contractor negotiators are risk averters. They are willing to accept a lower profit with a greater sharing of the risk between the two parties. The sharing of risk between the government and the contractor is reflected by the type of contract used to support developmental programs. The contract types available for this purpose range from the firm-fixed-price contract to the cost-plus-fixed-fee one. The firm-fixed-price, fixed-price-redeterminable, fixed-price-incentive-fee, cost-reimbursement, cost-plus-incentive-fee, and the cost-plus-fixed-fee contract types were considered in some detail. The contractor bears the highest degree of risk under the fixed-price contract, and the lowest under the cost-plus-fixed-fee type. The fixed-price-redeterminable contract type is seldom used by the government. The claim is that since the contract is subject to redetermination at periodic intervals the contractor is

encouraged to operate in an inefficient manner and to incur unnecessary costs. The validity of such a charge for a given contract would depend on the adequacy of cost visibility and control. If proper control can be maintained, this type of contract may be the answer for the support of high-dollar-developmental procurements. In a free-enterprise economy, profit maximization is considered to be the goal of the individual firm. Profits need to be related in direct proportion to the magnitude of the risk borne. The profit incentive as related to incentive contracts was examined. Data indicated that incentive contracts have not been overly effective in coping with the cost-growth problem. Highly-dispersed profit distributions in an industry reflect the high degree of risk. Should firms consistently take high risks and not be rewarded, then they will either exit the industry or go out of business. Numerous departures could result in a detrimental loss of productive capacity in individual technical areas. For the government, the profit policy objective is to provide the contractor with an opportunity to earn a fair and reasonable profit. Fair and reasonable has meaning within the framework of the environmental factors for a given procurement. No reason exists to expect the profit for an advanced development contract to conform to an average figure. The final figure must be based on an analysis of the unique combination of factors for the specific program being negotiated. Controversy has existed

over the actual level and trend of profits for defense contractors. In general, profit levels have fallen. This fact has led to a flight of capital from the defense industry. These conditions have been acknowledged, and it is anticipated that the profit rates on defense contracts will increase in the future.

Technically, a cost growth occurs when actual cost is greater than the initial estimate for a program. The very nature of scientific exploration as encompassed by the research and development spectrum tends toward cost-prediction errors. The initial estimates for a contract which are based on projection of costs into an unknown future are subject to a large degree of error. Cost growths are not the exclusive domain of the Department of Defense. From antiquity, a Roman example was considered, as well as some modern ones where commercial ventures have experienced cost growths. The causes of cost growths were classified as either preactivation or activation. Preactivation refers to the time period between technical and cost proposal preparation and the time the contract is signed by both parties. Activation refers to the part of the procurement cycle which includes contract administration and closure. The causes of cost growths as reported in the literature were listed in Table 5, beginning on page 88. Each factor was then discussed.

Historically, the FFP contract has been the type of support document deemed most desirable to procure supplies

and services for the government. Related to this preference was the emphasis placed on formal advertising as the preferred process for placing contracts. The combination did not serve well as supporting mechanisms for scientific programs. The multiple uncertainties inherent in research and development programs contributed to cost growths. A representative sampling of the efforts to cope with cost growths was examined. The attempts were classified under the headings of preactivation, activation, and environmental patterns. Preactivation measures considered techniques, such as type of contract, the "Should Cost" concept, design policy, contractual provisions, stimulation of competition, and multiyear procurements. Activation techniques included delegation of additional authority to program managers, control of design changes, use of mathematical science techniques in the management process, the Value Engineering Program, growth of management systems, improved financial status of contractors, and efforts to rate contractor performance. Under the environmental patterns heading, factors were considered, such as centralization and decentralization of decision making, the implementation of the program definition phase, the total package procurement plan, and commonality. One measure of cost performance effectiveness for contractors is to compare the actual program costs with those estimated for the program initially. Three sample time periods were examined to determine if a trend could be detected. The trend disclosed

was one of increased cost growths. Thus, over the twenty-year period examined, measures to reduce cost growths have apparently not been too effective.

Four parameters and their interactions emerged as the key conceptual issues. The parameters were time, uncertainty, information, and cost. In communication theory, information relates to the number of choices available to the decision maker, or to the number of possible events that could occur. Thus, this term does not encompass meaning. The expression, informational efficacy, was adopted to convey meaning or value. Entropy is a measure of the amount of information in a system; in particular, it encompasses the number of choices available to the decision maker. Entropy relates to the degree of randomness of the information, not to informational efficacy. As entropy increases, information increases, uncertainty increases, freedom of choice increases, but the informational efficacy decreases as related to a specific data source. In a closed system the tendency is for entropy to increase. What is needed is a source of negative entropy to counter this propensity. In other words, the informational efficacy of the data in the system needs to be augmented. As the entropy or number of choices increases, the total uncertainty in the situation increases. The amount of uncertainty as to the occurrence of any individual event can be measured by probability. The factor permits the entropy for a probability distribution to be measured. These

concepts in conjunction with the concept of economic cost permitted a conceptual cost model to be developed. A key assumption of the model was that the effective cost for a developmental program may be represented by the ratio of target costs to the informational efficacy of the data in a closed system. Manipulation of the conceptual cost model demonstrated several principles. As the level of informational efficacy increases, the costs for a developmental program decrease. Over time, the cost for informational efficacy increases at an increasing rate. This cost is essentially the price of program administration. These cost relationships imply that a total economic cost approach is imperative. Suboptimal decisions can occur, if the economic program cost is considered in isolation. Rather, the total-cost approach is the touchstone. The total-system approach dictates that total economic cost will be minimized. In this context, a cost growth may be warranted if the over-all cost will be at a minimum. The role of the management information system is to provide proper cost visibility. The characteristics of an effective management information system were considered. A computer program may be developed to simulate the contract administration process as reflected by the conceptual cost model. The parameters of time, cost, uncertainty, entropy, and informational efficacy may be manipulated to simulate various world states. Basically, simulation permits the identification of successive states of the situation by the

repetitive application of the rules that govern a system. Using the model, no magic number can be derived for the future cost of a program. The best estimate will still intrinsically incorporate an indeterminate measure of uncertainty. The value of the model relates to its explanatory capabilities. The model illustrates the relationship between program cost and the disorder in a contract administration system. This disorder is created by warp factors in the current and future environments. The objective is to better understand cost growths and their causes. The logical consistency of the assumptions of the model were checked by symbolic logic. They were found to be logically consistent.

A methodology for the evaluation of cost estimates for developmental programs was examined. The preparation and evaluation of cost estimates to a degree is an art, not a science. However, management and financial science techniques can aid the decision maker in the process of orderly and logical thinking. The objective of such techniques is to reduce uncertainty, rather than its complete elimination. Three techniques used for the estimation of costs were examined briefly. The three approaches are the industrial engineering, statistical, and analogy. For most situations statistical procedures are preferred. This preference accrues primarily from the flexibility and generality of the approach. Some aids to cost analysis were considered, such as the 80-20 Rule, the law of large numbers, and the fallacy

of composition. The conclusion emerged that cost and risk analysis should be combined into cost uncertainty analysis, and each aggregate cost estimate should include a section which evaluates cost uncertainties. The decision tree, a graphical-sequential technique, was adopted as a decision tool. The application of probabilities to the decision-tree choices permitted the calculation of the probability that a given event will occur. New information which reduces the degree of uncertainty will often lead to the revision of probabilities and permit the individual to modify his previous decision. Bayes' Theorem was applied to illustrate the approach. The value of new information gathered for the reduction and resolution of program uncertainty was demonstrated. Also the use of an individual's utility function as an aid to decision making was considered. In conclusion, the impossibility of eliminating uncertainty in the decision-making environment is acknowledged. However, the efficacious manager will take action to reduce it to a minimal level.

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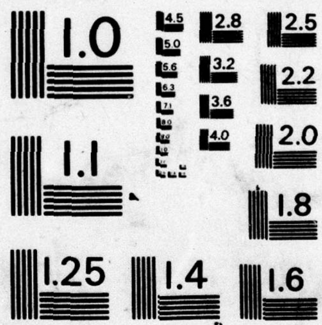
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GLOSSARY

Algorithm: A sequential procedure for performing a mathematical routine in a given number of steps.

Bellman's Principle of Optimality: The principle requires that all decisions in a sequence must maintain the integrity of the initial decision. A necessary assumption is that the initial decision established an optimal policy.

Bias Effect: The contractor inflates the target cost for an incentive contract. A contract underrun is caused by this inflation of cost estimates, rather than by cost reduction efforts.

Buy American: A congressional Act that requires items purchased for public consumption to be mined or produced in the United States.

Certainty: Each decision leads to a predictable outcome. No doubt as to the final outcome is possible.

Cost Optimism: A contractor bids low in an effort to convince the contracting agency that a program's costs are low enough to be funded.

Cost Visibility: Management efforts are expended to insure that program costs are known and under control.

Davis Bacon: An Act governing the payment of wages under Government construction contracts. Substandard wages are prohibited.

Dynamic Programming: An orderly approach for searching out a specific sequence of decisions which optimizes some predefined objective function.

Engagement: Continuous communications are maintained with a contractor in order to effect adequate program control.

<u>Entropy</u>: The term encompasses the number of choices available to a given decision maker.

<u>Heuristic</u>: The term involves the systematic use of trial and error methods for obtaining solutions to problems.

<u>Incentive Effect</u>: Cost reduction and control are the goals of incentive contracting. The incentive for the contractor is increased profits. The incentive effect is operative when increased profits result from contractor efforts to control and reduce costs.

<u>Information</u>: The term relates to the number of choices available to the decision maker. The amount of information is measured by the logarithm of the number of available choices.

<u>Informational Efficacy</u>: This expression refers to the content or meaning of a unit of information. It is synonomous with order in a closed system.

<u>Negentropy</u>: A measure of the amount of informational efficacy present in a closed system.

<u>Risk</u>: The totality of outcomes for a given variable can be described by a probability distribution.

<u>Stochastic Process</u>: A random process which leads to more than one possible outcome. The possible occurrence of any given outcome is uncertain.

<u>Uncertainty</u>: The known is completely dominated by the unknown. The probability distributions for future events are not known.

<u>Walsh Healey</u>: An Act passed by Congress in 1936 that prohibits the payment of substandard wages to workers under the provisions of Government supply contracts. It provides the same coverage for the supply area that the Davis-Bacon Act guarantees to construction workers.

<u>Warp Factors</u>: The term includes environmental factors, such as excessive wage settlements, unexpected technical problems and communication problems, which are at best only partially under the control of the program manager for a given contract.